JET PROPULSION
LABORATORY

(NASA-CR-156955) [FLIGHT AND MISSION OPERATIONS SUPPORT FOR VOYAGER SPACECRAFT LAUNCHING AND VIKING-MARS MISSION] (Jet

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16. Abstract

This report summarizes the activities of the Jet Propulsion Laboratory during fiscal year 1976-1977. Areas covered include ongoing and planned flight projects, DSN operations and development, research and advanced development in science and engineering, and civil systems projects. In addition, administrative and operational facilities and developments are described.

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DIRECTOR'S MESSAGE

This report on last year's activities points toward the future of the Laboratory, a future in which I feel we will provide unique services to the nation in the exploration of the solar system, the practical utilization of space, and in the development of new energy technologies.

The launches of two NASA Voyager spacecraft and the highly successful support of the Viking Mars mission were perhaps our most visible efforts to the outside world. But we were increasingly active in other areas, notably in support of solar-electric technology development and aspects of enhanced coal utilization and electric and hybrid automobile development.

In the photovoltaics area of solar-electric technology, we are steadily approaching the goal of providing solar cell arrays at a cost competitive with other energy sources.

We are preparing a new NASA earth satellite, Seasat-A, designed to explore the practicality of monitoring the surface of the world's oceans with a sophisticated array of microwave instruments. They would provide a broad spectrum of new data on ocean conditions for use by weather analysts, shipping lines, fisheries and oceanographers, and those involved in arctic operations.

Another NASA earth satellite project we are involved in is IRAS, the Infrared Astronomical Satellite, an exciting project that will map infrared sources in our galaxy and beyond. This is an international mission, as the Netherlands will provide the spacecraft and a British tracking station will monitor the satellite.

A new deep space project assigned to the Laboratory is the Galileo Mission. A single spacecraft will be launched from the Shuttle and arrive at Jupiter in 1985. A probe, developed by the NASA Ames Research Center, will be detached to penetrate the turbulent Jupiter atmosphere and radio data back to the spacecraft, which will orbit Jupiter for a year to study the planet and its satellites.

In the future, we may be flying a mission to study the sun's polar region from two spacecraft, one U.S. and one European. We would use the gravity-assist technique at Jupiter to hurl the spacecraft out of the ecliptic plane and send them arcing back toward the sun.

To plot the future of the Laboratory and insure that we carefully develop the potential of space flight, I consolidated several major activities into a single Office of Technology and Space Program Development. This office is giving us a wide-ranging look at the uses of space technology; and the development of instruments, techniques and materials, and possible flight missions of the future.

The Laboratory is achieving the technical results expected of us; our future holds unusual opportunities for valuable contributions to the nation if we can continue our successful pattern in new as well as familiar fields.

Bruce Murray

Bruce Murray
Director

FLIGHT PROJECTS

Major flight project activities at the Laboratory during the 15 months ending in September 1977 included

(1) Launch of two Voyager[1] spacecraft on flyby missions to Jupiter and Saturn.
(2) Continuation of mission operations support and analysis, and reduction of data from the Viking spacecraft.
(3) Continuation of development of an ocean observation satellite, Seasat-A, including mission operations and data dissemination planning, leading to a 1978 launch.
(4) Initiation of a joint international project, the Infrared Astronomical Satellite (IRAS), with the Netherlands and the United Kingdom.
(5) Completion of preliminary studies and plans for a Jupiter Orbiter Probe (JOP) mission that was approved as a new project start in Fiscal Year 1978 for launch in 1982.

JPL continued to provide significant flight operations support to Pioneers 10 and 11 and mission operations support on the joint West German U S Helios missions investigating the sun to within 0.30 astronomical unit (AU) of the surface

Voyager

Two Voyager spacecraft were launched by Titan Centaur launch vehicles on August 20 and September 5, 1977, from Cape Canaveral, Florida. The spacecraft are on trajectories that will result in closest approach encounters of Jupiter in March and July of 1979 and Saturn in November 1980 and August 1981 Each carries science instruments that will support eleven complementary investigations of the planets, their satellites, and interplanetary and the interstellar media.

The basic objectives of the project are to increase knowledge of the origin and properties of the two largest planets of the solar system and to gain additional information on interplanetary space in the outer solar system. Emphasis is placed on obtaining data on the two planets, their satellites, and the rings of Saturn

Voyager is an extension of the Mariner spacecraft family, augmented to meet requirements of 4 or more years of operational life, longer-range communications, precision navigation, solar-independent power, and resistance to the radiation fields of Jupiter, and to provide in-flight reprogramming capability to support the science investigations. On-board computer subsystems will sequence on-board operations to differing data acquisition requirements at Jupiter and Saturn, and during other mission phases The use of X-band and S-band communication frequencies and a large directional antenna permits data to be returned at very high rates from both Jupiter and Saturn Data return should be easily achieved to at least 20 AU (3 billion kilometers), reached 8 years after launch

Power for operation of the fully attitude-stabilized spacecraft is provided by radioisotope thermoelectric generators developed by the Energy Research and Development Administration (ERDA)[1] After jettisoning the propulsion module that supplied the final velocity increment for the Jupiter trajectory, the spacecraft weighed approximately 825 kilograms including 115 kilograms of science payload

The primary spacecraft activity since June 1976 was system level tests and operations, including assembly and test of the Proof Test Model (PTM) and launch vehicle interface checkout at the Eastern Test Range (ETR) in April and May 1977

Voyager 2, the first spacecraft launched, experienced early in-flight problems involving science boom deployment and attitude control software These problems were worked out on Voyager 2, and changes were made to the Voyager 1 boom deployment hardware and on-board software that both corrected and avoided problems experienced by Voyager 2

The largest single mission operations task is generation and verification of the sequence programs that are transmitted to and executed by the spacecraft

The Voyager trajectories will provide excellent observation opportunities for Jupiter's Galilean satellites and for Saturn's largest satellite, Titan Detailed design of the Jupiter observation sequences began in early 1977

In late 1975, NASA asked that the Voyager Project provide a "Uranus option" This option, now incorporated into the mission design, allows for a decision to be made on the Voyager 2 trajectory before Saturn encounter. Voyager 2 can repeat Voyager 1's mission, or it can take an alternate course that leads to an encounter with Uranus in January 1986. The Uranus option will be exercised only if Voyager 1 accomplishes all its objectives at Saturn, and if Voyager 2 is healthy enough and the expendables can be budgeted to undertake the additional 4-year flight to Uranus.

[1] Formerly designated Mariner Jupiter Saturn 1977

[1] ERDA was incorporated into the Department of Energy on October 1, 1977

Voyager takes the measure of Saturn's rings in rendering showing a milestone in the mission to the outer planets

Viking

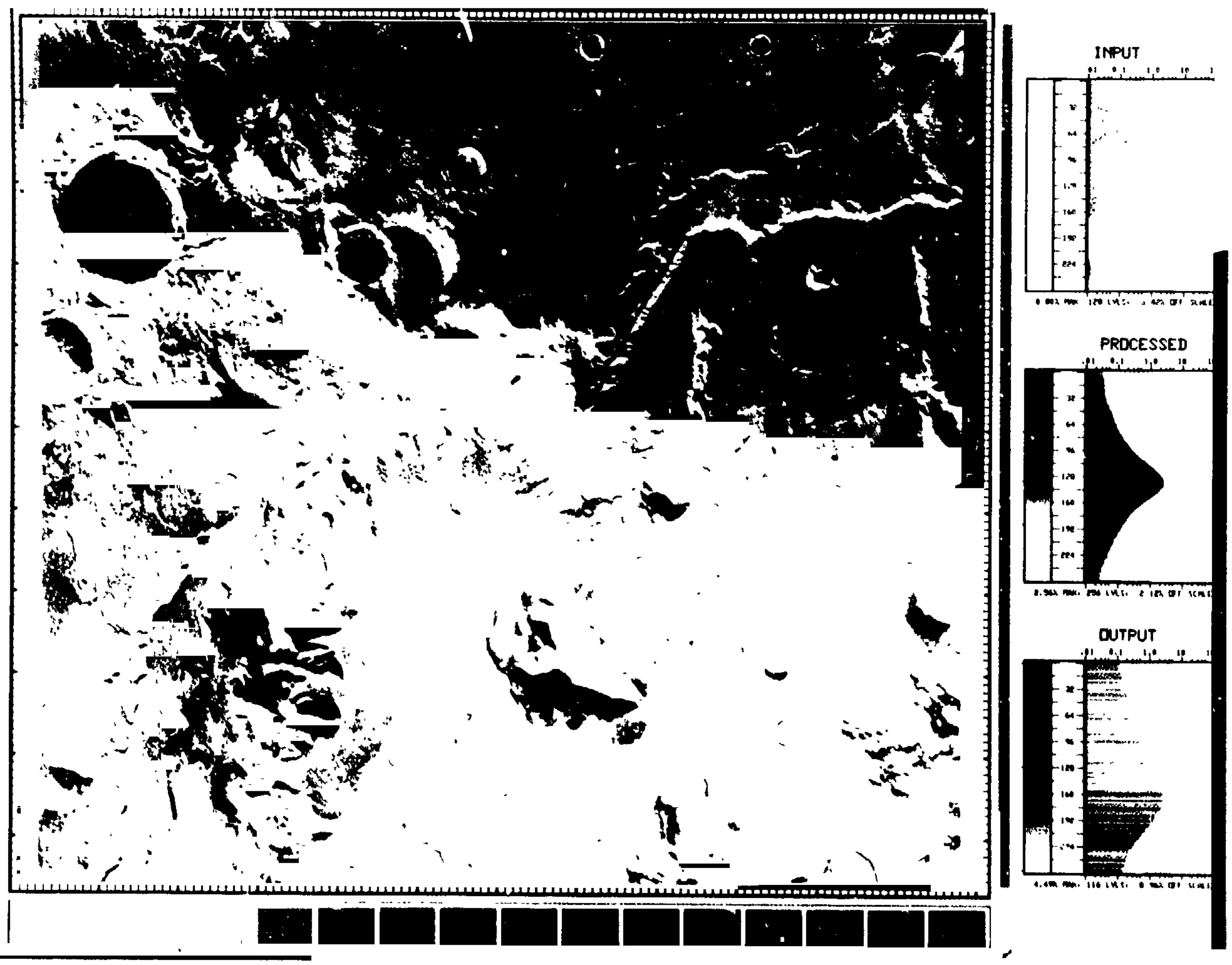
Viking was designed to orbit the planet Mars and to land and operate on its surface. Two identical spacecraft were launched in 1975, each consisting of an orbiter that carried a sterilized lander. The two landers are the first U.S. spacecraft to operate on the surface of another planet.

Langley Research Center has overall management responsibility for the Viking Project. The Lander System was developed under contract by Martin-Marietta Aerospace, and Lewis Research Center had responsibility for the Launch Vehicle System. JPL's assignment was development of the orbiters, the Tracking and Data Acquisition System, and the Mission Control and Computing Center System.

Both spacecraft were launched from Cape Canaveral on Titan Centaur launch vehicles in late summer 1975. Viking Orbiter 1 was placed in orbit on June 19 and Orbiter 2 on August 7, 1976. The Site Certification Team considered the original landing site for Viking 1 unsafe after studying high-resolution images of the area. Nearby sites were examined, and the first landing on Mars occurred on July 20, 1976, on the western slope of the Chryse basin at 22.5°N, 47.9°W.

The planned landing site for Viking 2 was also considered unsuitable when high-resolution images became available. Certification of a new landing site was accomplished in time for a landing on Mars on September 3, 1976, at 48.0°N, 225.7°W.

Each orbiter has exceeded 2 years of active flight operations with few anomalies or failures. At the time of their launch, the Viking spacecraft were the most complex planetary spacecraft developed. Four failures have been identified on the two orbiters, with only one having had significant influence on operations.



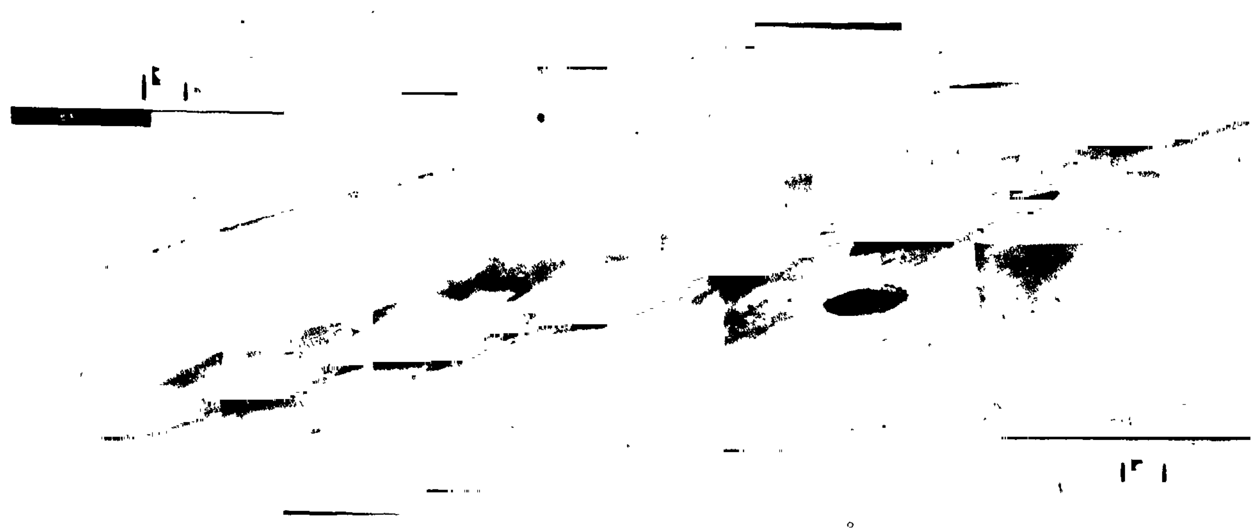
A variety of geological formations is evident in computer processed view from Viking Orbiter. Channel running through center of picture may have been caused by flowing water early in Mars' history.

The Viking Project primary mission ended on November 15, 1976, several weeks before superior conjunction. Several weeks after conjunction, telemetry and command communications capabilities were reestablished, and extended mission operations began They will continue through September 1978. All four flight systems are operating, and plans to prolong operations through the end of 1978 are under consideration by NASA.

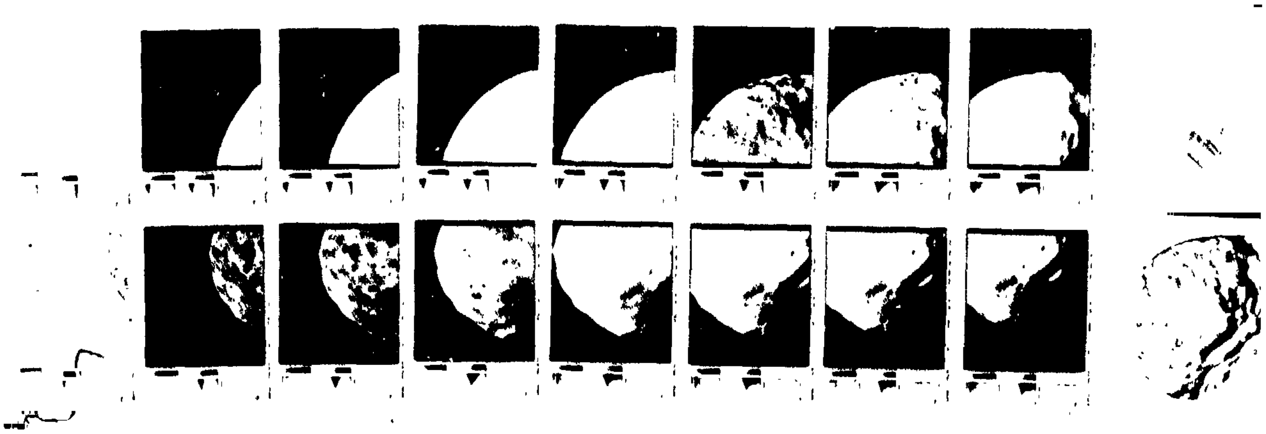
Both Viking missions have been successful beyond expectations. With a single exception, the science instruments have acquired more than the data planned for. Only the seismic experiment has been a disappointment: the seismometer on Lander 1 could not be uncaged after landing, and the other has detected only one event that may have been Marsquake.

The three biology investigations discovered unexpected and enigmatic chemical activity in the Martian surface material. The gas chromatograph mass spectrometer found no sign of organics to its level of sensitivity, but it did provide a precise and definitive analysis of the composition of the atmosphere and found previously undetected trace elements. The elemental composition of the surface material has also been measured by the X-ray fluorescence spectrometer, which continues to analyze soil samples. Measurements of some physical and magnetic properties of the soil have been made. The composition and physical properties of the upper atmosphere were also measured during the entry of the two landers.

Nearly continuous monitoring of weather at the landing sites is being carried out. The weather in the Martian midsummer was found to be repetitious, but with the passage of the seasons it has become both variable and more interesting. Cyclic variations in weather patterns (probably the passage of alternating cyclones and anticyclones) have been observed. Atmosphere temperatures at the southern landing site



Mosaic of Viking Orbiter 2 pictures of Mars shows north polar ice cap and the large crater Korolev.



Overlapping series of images obtained by the two cameras on Viking Orbiter during close pass of the Martian satellite Phobos.

have been as high as −31 C at midday, with the predawn temperature being −86 C. By way of contrast, the diurnal temperatures at the northern site during the midwinter dust storm varied as little as 4 C on some days. The lowest predawn temperature was −124 C, approximately the frost point of carbon dioxide. Frost was not detected by Lander Imaging Team members until near the end of winter.

The semiannual variation of barometric pressures, resulting from condensation and sublimation of atmospheric carbon dioxide at the polar caps, has been found to be unexpectedly large; the maximum and minimum mean daily pressures observed by Lander 1 were 6.7 and 9.5 millibars. Another surprise has been the generally small magnitude of wind velocities; neither lander has recorded a gust in excess of 100 kilometers per hour. Nevertheless, more than a dozen small dust storms have been observed by orbiter instruments. During the southern summer, two large dust storms occurred about 4 earth months apart. Both obscured the sun at the landers for a time and hid most of the planet from the orbiter cameras.

Photographs from landers and orbiters have surpassed expectations in quantity and quality. The landers have provided the first closeup look at the surface, have monitored variations of atmospheric opacity over more than six tenths of a Mars year, and have determined the mean size of the aerosols. The orbiter cameras have observed new and often puzzling terrain and provided clearer detail on known features, including color and stereo observations in some instances.

The infrared thermal mappers and the atmospheric water detectors on the orbiters have acquired data almost daily, observing the planet at high and low resolution. This massive quantity of data will require considerable time for analysis and understanding of the complex global meteorology of Mars.

Analysis of radio signals from landers and orbiters, including Doppler, ranging, and occultation data, and the signal strength of the lander-to-orbiter relay link has provided a variety of valuable information.

Other significant discoveries of the Viking missions include the following.

(1) Nitrogen, not previously detected, is a significant component of the Martian atmosphere, and the enrichment of the heavier isotope relative to the lighter implies that atmospheric density was much greater in the distant past.

(2) Changes in the Martian surface occur extremely slowly—at least at the two landing sites. Only one very small change has been observed in 14 months.

(3) In the winter, the surface temperature over much of the polar cap falls considerably below the freezing point of carbon dioxide (about −123 C), corresponding to the atmospheric pressure and even further below the temperature of the upper atmosphere. This remarkable phenomenon, observed at both poles, is not understood, but it probably indicates that atmospheric carbon dioxide is frozen in the cap more rapidly than it is supplied, so that the lower atmosphere over the cap is mostly argon and nitrogen.

(4) The residual north polar cap is composed of water ice. The composition of the permanent southern cap has not been determined, but it may not be exclusively water. The marked asymmetry between the two poles appears to result from global dust storms in the southern summer.

(5) The greatest concentration of water vapor in the atmosphere is near the edge of the north polar

Viking Lander 1 touched down only a few meters from this large Martian boulder, later nicknamed "Big Joe." The rock is about 3 meters across and 1 meter high.

Variety of rock types photographed by Viking Lander 2 in Utopia Planitia in the far north of Mars. Shadow in left foreground was cast by lander's meteorology instrument.

cap in midsummer. From summer to fall, the peak concentration moves to the equator, with relatively little change in global abundance. In the southern summer, the entire planet is dry, probably also an effect of the dust storms.

(6) The density of the inner satellite, Phobos, is very low (approximately 2 grams per cubic centimeter), perhaps implying an asteroidal origin, and its surface is marked with at least two families of parallel striations, probably resulting from fractures in the body upon impact with another object.

(7) Measurements of the round-trip time of passage of radio signals between earth and the Viking spacecraft made when Mars was beyond the sun (near solar conjunction) have determined the amount of delay of the signals by the sun's gravitational field. The result confirms the prediction of Einstein to an accuracy of ½%—four times greater than any previous test.

Seasat-A

The Seasat-A Project was initiated in 1974 by NASA's Office of Applications after several years of study, with the Laboratory being assigned project management responsibility. The concept of a satellite dedicated to the study of the world's oceans by remote sensing evolved from meetings and conferences involving potential user agencies and academic and industrial scientists. The meetings led to establishment of the Seasat Users' Working Group to define the final satellite concept and instrument payload. The instruments selected for Seasat-A were drawn from this background.

A principal product of this proof-of-concept mission will be an objective assessment by oceanographic and meteorological scientists of the utility of these measurements to physical oceanography, climatology, meteorology, and marine technology. Seasat-A is scheduled for launch in May 1978. The standard mission will last 1 year, with sufficient expendables for 2 more years of operations.

The first active microwave instrument selected for Seasat-A was a short-pulse radar altimeter. Precision altimetry from space offers the potential of remotely monitoring current systems, storm surges, wind setups, and tides. The Seasat-A radar altimeter evolved from a series of predecessors, both aircraft and satellite-borne. The nearest ancestor is the GEOS-3 altimeter, the design of which has been improved for Seasat to allow a height precision of ± 10 centimeters. Processing of the return pulse will also yield an estimate of sea state.

A second active instrument is the wind field scatterometer, which will measure wind speed and direction. The use of radar backscatter at K-band frequencies to measure surface wind stress has been demonstrated by aircraft tests and a Skylab experiment The instrument is expected to measure winds up to 20 meters per second (approximately 50 knots).

The third active instrument is the Synthetic Aperture Radar (SAR), an imaging device to provide data on ocean waves, coastal regions, and sea ice. The derivation of ocean wave directional spectra from SAR images should provide a capability of importance to wave climate and propagation studies, and to studies of wave diffraction and refraction in shelf and island regions. The study of coastal processes and ice, both sea ice and large glacial provinces, is expected to benefit from SAR data, particularly in light of the instrument's all-weather capability.

The five-channel Scanning Multifrequency Microwave Radiometer designed for Nimbus-G was added to Seasat-A to measure sea surface temperature on a global scale, day and night, through clouds and light rain, for climatological and ocean dynamics studies. Measurements at the several microwave frequencies will yield information on liquid water and water vapor column densities, sea surface winds, and potentially useful sea ice signatures.

A visual infrared imaging instrument, intended primarily to provide feature recognition, clear-air, sea-surface temperature calibration data, and perhaps precipitating cloud identification in support of the microwave instruments, completes the Seasat-A payload It is a modified version of the well-proven ITOS series of imaging radiometers.

The satellite, being built and tested by the Lockheed Missiles and Space Company, Sunnyvale, California, is a modified version of the Agena. The Agena "bus," which doubles as the launch vehicle final stage, provides power, telemetry, attitude control, and orbit-adjust support to the sensor module on which the instruments, electronics, and antennas are mounted. The satellite weighs 2400 kilograms and measures some 13 meters in longest dimension.

Telemetry, command, and tracking are provided by NASA's Satellite Tracking and Data Network (STDN). The satellite will transmit data at three rates on two separate S-band carriers. All data except those produced by the synthetic aperture radar are transmitted in real time at a 25-kilobit-per-second rate or played back from two on-board tape recorders at 800 kilobits per second. The playback mode is utilized to provide global coverage from a limited set of STDN stations Three of these stations can collect a complete global data set continuously by use of the satellite's playback capability. A fourth station at St. Johns, Newfoundland, is being equipped by the Canadian government to broaden collection of synthetic aperture radar data to areas of interest to Canadian scientists The synthetic aperture radar data are transmitted in real time and so can be received only when the satellite is within view of receiving stations equipped to receive them.

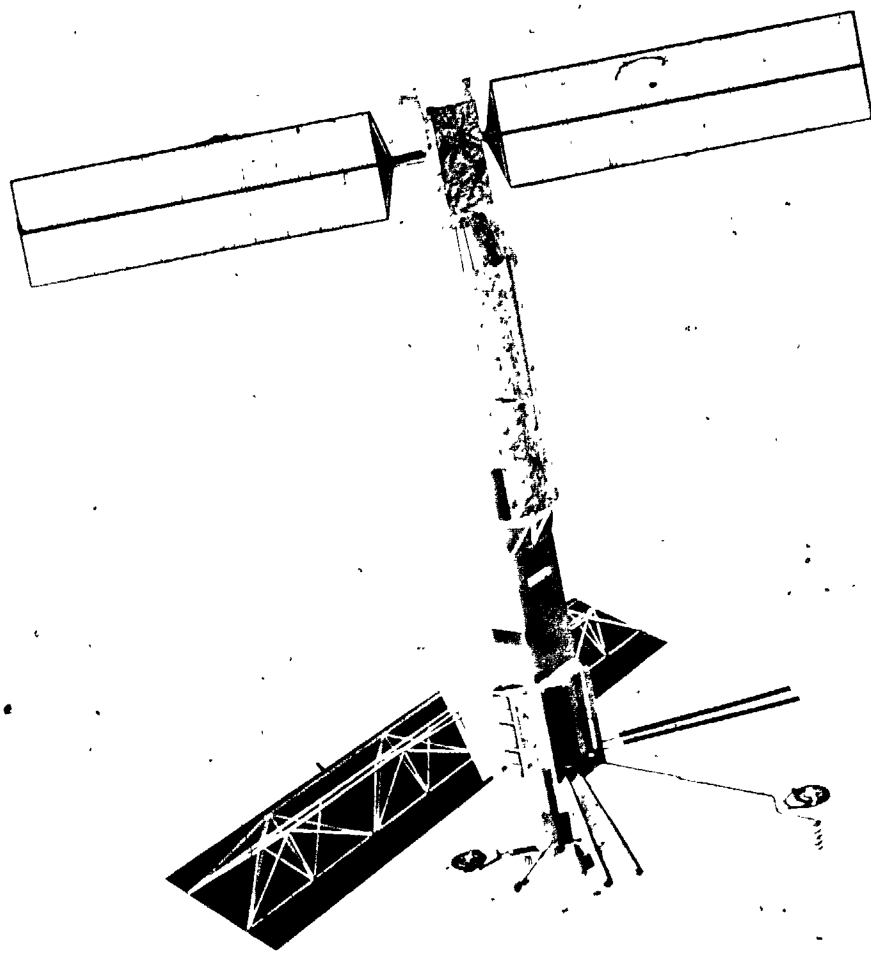
Three tracking systems are incorporated, the STDN S-band link carrier, a beacon to be used in conjunction with the Department of Defense TRANET array of tracking stations, and a passive retroreflector array mounted on the radar altimeter antenna to allow precision laser ranging.

The European Space Agency is equipping the Oakhanger tracking station in England to receive and process Seasat-A data for distribution to a segment of the European oceanographic and applications community.

The orbit selected for Seasat-A is high (108-degree) inclination, non-sunsynchronous, and nearly circular at 800 kilometers. The orbit design is such that a dense ground trace network (approximately 18½-kilometer spacing at the equator) will be achieved in approximately 5½ months of operation This dense coverage will allow the most accurate study of the marine geoid yet achieved.

There are two time scales for processing and analysis of Seasat-A data. First, a near-real-time data link, via commercial communication satellite, links the tracking stations with the Navy's Fleet Numerical Weather Central (FNWC) in Monterey, California. This link has been established, by mutual agreement between NASA and the Department of Defense, to allow assessment of the effectiveness of the Seasat-provided global temperature, wind field, and sea state data to FNWC's forecasting abilities. In addition to processing these data and incorporating them into its forecasting system, FNWC will provide intermediate data products to the National Oceanic and Atmospheric Administration's (NOAA) National Meteorological Center in Suitland, Maryland, for a similar evaluation effort.

A second path is followed by data intended for experiment team evaluation and general research purposes. This latter path has throughput times measured in days rather than hours or minutes. Its output is a fully annotated, geophysically processed global data set with all the ancillary data required for research purposes. During initial phases of the mission, experiment teams will evaluate the geophysical processing, feeding back changes to the initial algorithms to produce results of acceptable quality and reliability. After this initial period, geophysically processed data are provided to NOAA's Environmental Data Service for distribution to users.



Artist's concept of Seasat-A, over the Gulf of Alaska, where the oceanographic satellite will perform a major experiment.

IRAS

The Infrared Astronomical Satellite (IRAS) Project, a joint international project involving the United States, the Netherlands, and the United Kingdom, was approved in January 1977. The project will be jointly managed by JPL and NIVR, the Dutch Space Agency.

In addition to its role as project manager for the U.S., JPL will design and operate the facility that will produce an infrared sky map and source catalog containing as many as 1 million infrared sources. Ames Research Center is responsible for design and fabrication of the 60-centimeter-aperture telescope. The Delta 2910 launch vehicle and facilities at the Western Test Range will be provided by the United States. A system contract for design, fabrication, and test of the telescope has been awarded to Ball Brothers Research Corporation, Boulder, Colorado.

The IRAS spacecraft is being designed and built in the Netherlands. The United Kingdom will furnish the tracking station, where data will be returned from the satellite every 12 hours.

The IRAS mission will provide data for an unbiased all-sky survey using a number of broad infrared photometry channels, including the study of selected galactic and extragalactic sources and mapping of extended sources. This mission is a major step in developing and demonstrating a cryogenically cooled telescope in a space application. A single launch into a 900-kilometer-altitude, sun-synchronous orbit is planned for February 1981, with a design objective of at least 1 year of operational lifetime.

A reliable description of its contents is essential to an understanding of the universe. Many celestial objects are sources of strong infrared emission. It is not known whether all infrared emitters have been identified or how significant infrared emission is to the energy budget of the universe. Existing infrared surveys have not been sensitive enough to insure that all important classes of infrared emitters within the Galaxy have been discovered, or to include a significant number of extragalactic objects. Furthermore, there is no infrared all-sky survey for wavelengths greater than about 23 microns. The IRAS mission will provide the first survey of the entire sky at infrared wavelengths, impossible to achieve from ground-based observations.

In addition, the low background radiation environment achievable with a cryogenically cooled telescope allows this survey to be carried out with unprecedented sensitivity. At this sensitivity level, IRAS can detect the thermal emission from objects at great distances. Cool stars and regions of star formation would be detectable anywhere within the Milky Way. Spiral galaxies like the Milky Way should be detectable to distances of 200 million light years, and the brighter quasi-stellar objects to distances of 10^{10} light years. This should open up many new aspects of the Galaxy and lead to a better understanding of the structure and evolution of the universe.

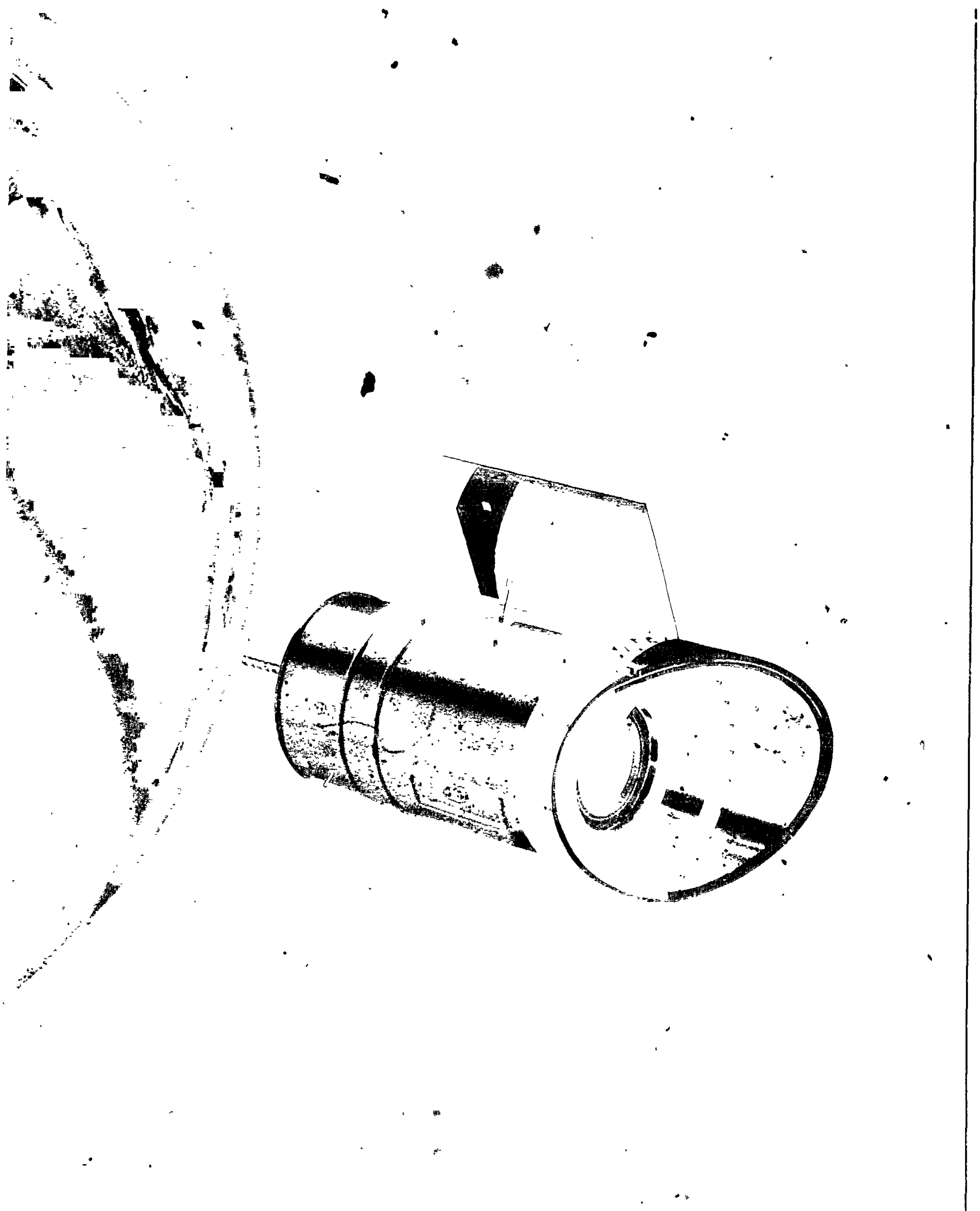
The invention of the telescope at the time of Galileo helped to expand man's perception of the universe from 4000 stars visible to the unaided eye to millions of stars and many nebulae and galaxies visible with a telescope. IRAS will extend the present knowledge, limited to about 1000 infrared sources at wavelengths beyond 8 microns, to information on as many as 2 million sources. It can be expected to lead to fundamental scientific advances in the understanding of the universe. IRAS is the Laboratory's first assignment in the field of space astronomy and provides a significant link to Caltech's traditionally strong astronomical program.

Other Project Activities

Preliminary studies continued on the Jupiter Orbiter Probe mission, to carry out investigations of Jupiter, including its atmosphere and satellites. This mission was approved by Congress as a new flight project beginning in Fiscal Year 1978 and will be managed by JPL, with the Ames Research Center being responsible for the probe. One hundred fourteen scientists were selected in August 1977 to participate in the mission. The Federal Republic of Germany has committed to development and delivery of the orbiter's retropropulsion module, along with a portion of the scientific instrumentation. JOP, scheduled for launch in January 1982, will be the first deep space mission launched by the Space Shuttle.

A Solar Polar mission is being studied by JPL as a potential new start in FY'79. This mission, designed to explore regions of space above and below the plane of the ecliptic and to observe the polar regions of the sun, would be a cooperative venture with the European Space Agency. An Out-of-Ecliptic Science Working Group was formed in late 1976 to recommend on the science objectives of the mission. This Group's activities and the JPL studies have been coordinated with parallel efforts by the European Space Agency (ESA). In April 1977, NASA and ESA jointly issued an Announcement of Opportunity for scientists to propose investigations.

Preproject studies on a Lunar Polar Orbiter mission to carry out a global geochemical survey of the moon were suspended early in 1977, when NASA determined that the mission would not go forward as a proposed FY'78 new start. This mission is again under consideration, as an FY'79 new start candidate. With



The Infrared Astronomical Satellite will carry a liquid-helium-chilled telescope that will collect data for use in an all-sky map of infrared sources. A single launch into a sun-synchronous orbit is planned for February 1981.

deferral of initiation by 1 year, the launch would occur in March–April 1982.

To assist NASA's continuing efforts to reduce the costs of future missions by supporting development of standard subsystems, JPL has developed a standard radio frequency transponder, a command detector, a dry gyro inertial reference unit, and standard thrusters for use by near-earth and deep space missions. The inertial reference unit and standard thrusters are already in flight on Voyager, and the first near-earth versions of the standard transponder have been delivered to the Stratospheric Aerosol and Gas Experiment Project and the Seasat Project. In addition to those missions, standard subsystems have applications in projects such as the Solar Polar, Infrared Astronomical Satellite, Jupiter Orbiter Probe, Magnetic Field Satellite, Space Telescope, and Mars follow-on missions.

Support to the Pioneer and Helios Projects is continuing. The Pioneer missions are managed by Ames Research Center. JPL is responsible for spacecraft navigation, operations, and analysis, and tracking and data acquisition support. The U.S.-West German joint Helios Project is co-managed on behalf of the United States by the Lunar and Planetary Programs Office at NASA Headquarters. JPL supports mission operations, tracking and data acquisition, mission control and computing, and navigation. Pioneers 6, 7, 8, and 9 were occasionally tracked on their heliocentric orbits between Venus and Mars, primarily to sample the science and engineering data and verify orbits. Pioneer 10 was tracked frequently (less than 16-hour gaps) on its way out of the solar system, and Pioneer 11 received daily tracks for data gathering and orbit refinement preparatory to maneuvers leading to a Saturn encounter in September 1979. Training and navigation activities started to accelerate in support of the Pioneer Venus mission, with two launches in 1978. Both Helios spacecraft were supported in conjunction with the German tracking station at Weilheim and under control of the German Space Operations Center at Oberpfaffenhofen, near Munich. Deep Space Network and Mission Control and Computing Center support varied between 100 and 200 hours per week for both probes, and peaked at the semiannual superior conjunction, perihelion, and inferior conjunction epochs.

The centralized computing services within JPL are the Mission Control and Computing Center (MCCC), the General Purpose Computing Facility (GPCF), and the Administrative Computing Facility (ACF).

Requirements for support to current projects have exceeded the capacity of existing computers, and a significant part of the nonreal-time mission-operations computing for the Viking Extended Mission is being provided from a commercial service bureau in Santa Clara, California. This has avoided the need for expansion of existing computing facilities, and it demonstrates the usefulness of the technology that has emerged in data transmission and computer networks.

Significant attention has been given to technical and managerial techniques that can be applied to the software development process. Improvements have resulted so that successfully meeting schedule and cost objectives has been the common case for software development for the Voyager Project, even in rather demanding applications such as the Real Time Telemetry System. Benefit has also derived from the use of improved design languages and programming standards.

Investigation of solar phenomena, such as the huge solar flare seen in this dramatic picture taken by Skylab, is playing an increasingly large role in the Laboratory's flight missions.

TECHNOLOGY AND SPACE PROGRAM DEVELOPMENT

The primary objective of Technology and Space Program Development is to foster challenging space projects of the future to be implemented by the Laboratory's program offices and technical divisions. Another objective is to identify, and develop leadership in, technological and scientific fields that will be important in the future.

Strategic Planning and Studies

Through mission studies workshops, conferences, and advisory groups, strategic planning for future space projects produced several advanced mission concepts, including the following.

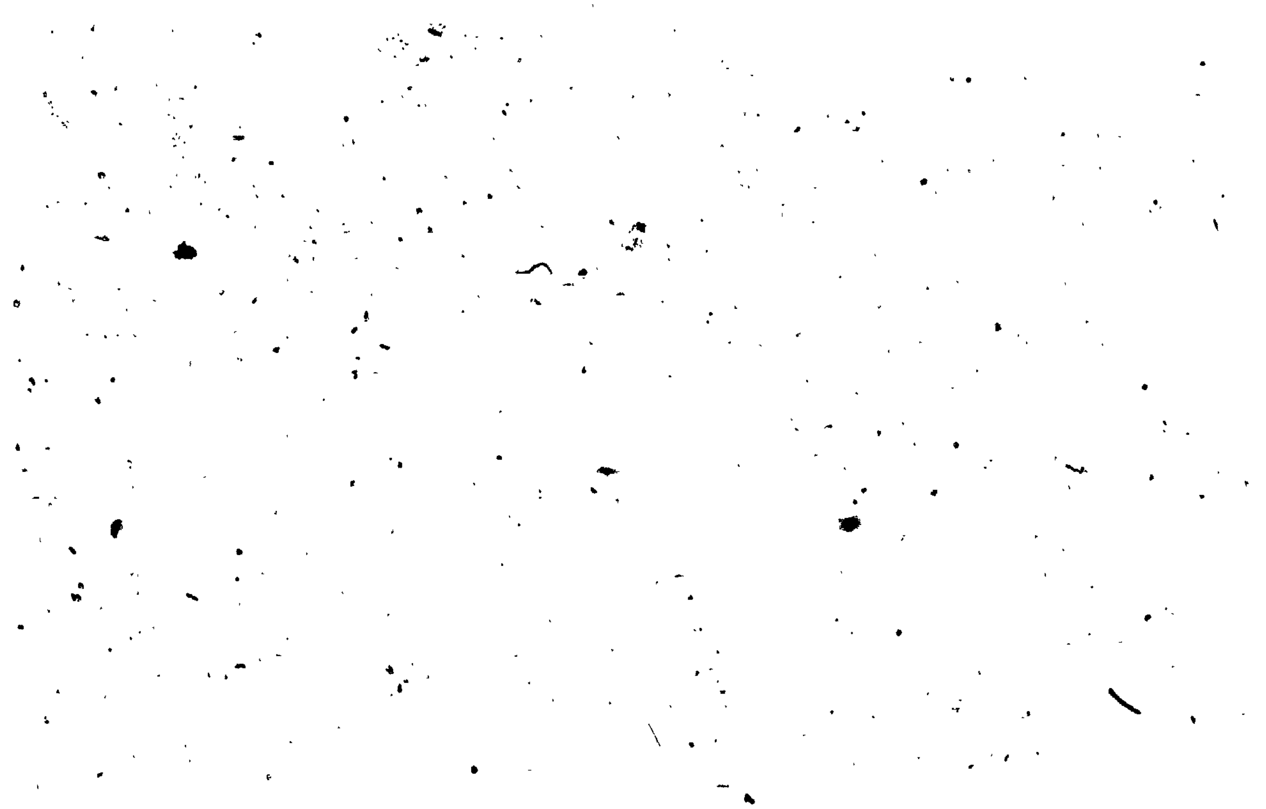
Extraplanetary Flight

A spaceflight mission out of our planetary system could provide direct measurements of the heliopause (where the solar wind terminates against the interstellar medium), the interstellar medium itself, and low-energy cosmic rays; spectroscopic observations of interplanetary gases; and great improvements in stellar distance measurements. Secondary mission objectives include the investigation of Pluto. Heliocentric hyperbolic escape velocities of 50 - 100 kilometers per second or more were considered. The basic mission duration would be 20 years, with the possibility of an extended mission of 50 years. A system using nuclear electric propulsion (NEP) was selected as baseline. The most promising alternatives are ultralight solar sails or laser-illuminated sails, with the lasers in earth orbit.

Saturn Mission

A comprehensive mission concept was outlined, consisting of a Saturn orbiter, atmospheric entry probe, and a soft lander on Titan, the Saturn moon with a promising atmosphere. Lesser missions were considered, ranging down to a flyby bus with a Saturn probe.

The Space Shuttle launch capability for Saturn flight trajectory modes after 1985 was determined weighing these alternatives: (1) ballistic, using a single Shuttle launch, or two or three launches with on-orbit assembly of several Interim Upper Stages (IUS), (2) gravity-assist, using either a Venus flyby or an applied velocity followed by an earth flyby; and (3) low thrust, using ion drive or a solar sail.



Possible trajectory for a mission to orbit Saturn and put an instrumented lander on its satellite Titan.

Technical studies included consideration of entry and terminal descent/landing at Titan and Titan lander/Saturn orbiter communications.

Space Program Development

Space Program Development is responsible for developing new flight mission concepts to the point where they can be approved as new starts, and for developing major areas of technology for application to a spectrum of missions.

Ion Drive Propulsion

A rocket engine using the principle of ion drive—or solar electric propulsion—was selected by NASA as the United States' prime candidate for powering interplanetary spacecraft in the 1980s and beyond in a competition with the alternative mode of using a solar sail.

Ion-propulsion spacecraft draws alongside a comet in rendering depicting one of several potential missions using new low-thrust propulsion techniques being developed at the Laboratory.

Ion drive was chosen over the solar sail concept for long-term, low-thrust space flight because of better performance, growth potential, and technical maturity born of a decade of solar electric developmental work at several NASA centers, including JPL. Both ion drive and solar sail studies were led by JPL scientists and engineers.

The ion drive spacecraft will utilize large, lightweight solar arrays to feed electric energy to a cluster of mercury ion engines. The engines provide thrust through the ionization of mercury vapor and subsequent high-voltage acceleration to achieve rocket exhaust speeds to more than 240,000 kilometers per hour. Although the thrust force is extremely low, the fuel efficiency is 10 times better than that of today's chemical rockets.

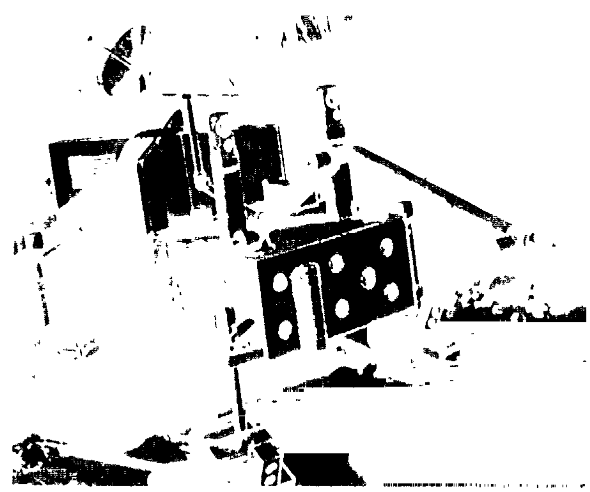
Its huge impulse capability from a small amount of fuel makes ion drive a likely workhorse spacecraft for heavy payload flights to Saturn and other outer planets, round trips to Mars, and tours to asteroids and comets. Several comets—Halley's, Encke, and Giacobini-Zinner—are being considered as targets for scientific investigation by an ion drive spacecraft launchable from the Space Shuttle in the 1980s. For cometary chases, speeds over 160,000 kilometers per hour would be required.

Comet Missions

In 1986, Halley's Comet will make its closest approach to earth in 76 years. An ion drive spacecraft was proposed for a 1982 launch to intercept the comet 3½ years later and place a scientific payload alongside or put a probe on the cometary nucleus, but that mission is likely to be delayed by NASA budget constraints. A 1985 mission either to the smaller comet Encke, or flying by Halley and going on to the nucleus of comet Temple, may fit better with programmatic and budgetary planning. That mission will require a project start in FY'81. Preproject advanced development to prepare for the project start is now underway at a vigorous pace.

Mars Missions

A 1984 Mars Rover mission study was made, outlining a follow-up exploration of Mars that would extend the Viking mission findings. The proposal, including the use of robotic roving vehicles to explore and analyze the Martian surface, was considered but now appears unlikely for budgetary reasons. Efforts aimed at a sample return in the late 1980s are continuing.



Mars Rover, cruising a selected area of the planet to seek information about its surface, would travel at least 100 kilometers during its year-long mission.

Solar Polar Mission

An international double spacecraft mission has been proposed to chart unexplored areas of the solar system from a new perspective above and below the plane in which the planets orbit the sun. That proposal moved from the study phase to being a likely project to be cosponsored by NASA and the European Space Agency.

The Out-of-Ecliptic (or Solar Polar) mission would be Shuttle-launched in February 1983, one spacecraft going below the south pole, the other above the north pole of the sun. They would be launched on a trajectory to Jupiter and use that planet's gravity to escape the ecliptic and swing back to the sun.

The 4½-year mission is expected to produce a scientific bonanza in knowledge of the sun's surface, radiation, magnetic field, and the heliosphere.

Solar Polar spacecraft approaches the sun during projected mission. The international dual-spacecraft flight will investigate hitherto unexplored areas of the solar system.

Seasat-B Study

The value of a follow-on to Seasat-A, designed to deliver real-time oceanographic data to commercial users, was outlined in a study report to NASA. Such a satellite, launched in the early 1980s, could provide improved sea condition information to shipping, oil, and fishing industries.

Technology Development

This program aims to determine technological themes of future value and to develop Laboratory leadership in these fields, both in space and earth applications.

Containerless Processing

Extensive research has been conducted on an acoustic positioning device to be used in a containerless processing facility to be flown on the Space Shuttle. First measurements of the first-order nonzero time average acoustic torque have been made. Acoustic torques allow the spinning of molten samples without contact for the purpose of degassing and shaping of molten materials. These data were used to design a containerless processing facility being flown on a KC 135 aircraft for short zero-g tests in preparation for the Space Shuttle flights.

Robotics

A fully integrated robot system including functions of vision, locomotion, and manipulation was steadily improved. With a single command, the robot has scanned

Prototype of robotic vehicles designed to explore planetary surfaces has stereo vision and a manipulator arm, and can move to avoid obstacles in its path.

its laboratory environment, automatically interpreted its laser input to detect obstacles, and located and picked up randomly placed object samples.

The demonstrated capabilities are all necessary for autonomous mobile planetary surface exploration and scientific sampling and have not heretofore been brought together in a single coordinated system. Similar systems could be applied to other space operations, including the assembly and servicing of large space stations where economic considerations rule out the use of men.

Superfluid Helium Cryogenics

A 5-year program has established the feasibility of using superfluid helium to cool scientific and engineering devices to temperatures below 2 Kelvins (about -455°F) in space. Such devices include superconducting gyroscopes for tests of general relativity, infrared telescopes, superconducting detectors, superconducting logic circuits and memories, and superconducting magnets for high-energy particle analysis. Superfluid helium was proved a superior cryogen in space performance and ease of application to nonsuperfluid cryogens. The first application of the superfluid system will be in the Infrared Astronomy Satellite, which will carry out a 1-year survey with a 60-centimeter telescope cooled to 10–20 Kelvins by the new system, and focal plane sensors cooled to 2–3 Kelvins. The Cosmic Background Explorer and Gyroscopic Test of General Relativity programs now under study would also make use of superfluid cryogenic systems.

Measurements of the properties of superfluid helium in zero gravity being made on board special NASA zero-gravity aircraft.

Visible and Ultraviolet Lasers

A new class of visible and ultraviolet gas lasers—smaller and lighter than previous UV-visible types—was developed to operate in a pulsed mode. The lasers are produced by excitation of high-pressure gas mixtures with a very short-duration electric discharge pulse. Two types of UV-visible lasers developed are the charge transfer molecular ion laser and the rare gas halide eximer laser. In both types, an inversion between molecular electronic states is produced by fast excitation transfer reactions of excited rare gas species produced in the electric discharge.

Test of new lasers demonstrates that smaller and lighter versions of the instrument are feasible for remote sensing applications.

Lasers have several advantages for use in remote sensing. Laser remote sensing does not require the sun as a source, the laser beam is coherent, and, combined with high power and pulsed, it can be used to do ranging to obtain high-resolution vertical and horizontal distributions of atmospheric molecules. Such lasers enable remote sensing of atmospheric constituents, trace species, pollutants and aerosols, cloud motions, and surface composition. Laser remote sensing also can be used to determine the size and albedo of asteroids from earth orbit and to determine surface properties in support of landed missions.

Advanced Imaging System

An experimental charge-coupled device (CCD) imager development program produced a three-phase, three-level, all-polysilicon gate structure for an 800 × 800 element sensor. A new step-and-repeat camera, necessary for production of these 800 × 800 element sensors, was placed on order for delivery early in 1978.

The improved CCDs will be used in planetary exploration, starting with the Jupiter Orbiter Probe (JOP) Orbiting System. Other applications will include observations from Spacelab, Space Telescope Wide Field Camera (ST/WFC), and Faint Object Spectrograph.

In cooperation with Caltech, a CCD camera is being tested and proven at Hale Observatory. Other CCD cameras are being readied for use at Lick, Cerro Tololo, and Kitt Peak Observatories under National

Science Foundation (NSF) sponsorship. Additionally, a microprocessor-based CCD camera was constructed on a design believed applicable to both the JOP mission and the proposed ST/WFC camera.

Airframe Noise Reduction

JPL-developed equipment for the study of airframe noise obtained noise source distribution results from flow about aircraft component models in a wind tunnel. The new technique does not require instrumentation of the model itself and is confined to the origin of the noise. A pictorial representation of the source distribution is obtained in as little as 5 minutes, depending upon the complexity of the model. Information obtained enables one to see at a glance which elements of an aircraft are most noisy, and enables rapid assessment of the effectiveness of design changes for noise reduction. All types of aircraft flow were examined. Results indicated that the wingtip vortex and flow separation may be more important in noise abatement than the well recognized trailing edge source.

Scanning Electron Microscope

A scanning electron microscope (SEM) based method was developed which successively irradiates selected components and small segments of a component in an integrated circuit chip with equal doses of electrons to determine the radiation sensitivity of each area. During a space mission, integrated circuits traveling through radiation belts are subject to degradation and failure. The relative radiation sensitivity of every circuit component now can be determined.

The method will be used in the JOP Project and also in quality assurance work for the Defense Nuclear Agency.

Advanced Power Processing

A long-lived power-processing system was developed for Voyager and future missions. Designed to regulate, control, and dissipate the power from three multihundred-watt radioisotope generators, the system provides 8-year minimum capability (previously 2 years were required) and is immune to single piece-part failure.

Information System Technology

An improved image data preprocessing and compression technique called cluster-compression was developed at JPL for use in future earth resources missions. By reducing data volume down to 1:100, cluster-compression techniques on future Landsat missions can enable large savings in image data communication, storage, and computer processing costs—over 200 million dollars per year, studies indicate.

Silicon Solar Cells

Breakthroughs in the fabrication of ultrathin, high-performance silicon solar cells have greatly increased the power-to-mass capabilities of solar arrays used in space. This technology makes feasible utilization of solar energy in the multikilowatt range. Processes to produce 50-micron-thick solar cells were developed and demonstrated at Solarex Corporation under JPL contract, with a pilot line capability of 3000 cells per month.

Possible applications of the cells include space power supplies for unique space laboratory functions, welding, construction, manufacturing, and interplanetary spacecraft travel with ion drive thrust systems. Lightweight solar arrays are a first-step requirement for a Solar Space Power System, which could gather the sun's energy, send it to earth using microwaves, and reconvert it into electrical energy for terrestrial use.

Gallium Arsenide Solar Cells

An efficiency of 17% was achieved with an Antireflection-Coated Metal-Oxide Semiconductor (AMOS) solar cell fabricated of gallium arsenide (GaAs) using a new processing technique. A polycrystalline GaAs wafer proved nearly as efficient as single-crystal GaAs solar cells, furthering hope that the AMOS processing will be applicable to deposited thin-film GaAs.

Distributed Computer Systems

A real-time distributed computer system for spacecraft data handling and control was designed and implemented. This Unified Data System (UDS) is under test in a feasibility breadboard used to simulate processing aboard a planetary spacecraft. Goals are to make multiple computer configurations more manageable, simplify interfaces, and increase ease of programming.

Voyager Spacecraft Antenna

Voyager spacecraft antenna hardware was fabricated, tested, and launched. The 3.7-meter (12-foot) diameter high-gain antenna is the largest yet built of low-thermal-expansion/high-strength graphite–epoxy materials.

Advanced Solid Propellants

Advanced compositions have been studied to increase the energy and thrust of solid rocket propellants and reduce emissions of contaminating chlorine compounds. A key ingredient of the new formulations is cyclotetramethylene-tetranitromine, known commonly as HMX.

The combustion properties of HMX and HMX-containing propellants are becoming better known through

studies conducted at JPL under NASA and U.S. Air Force sponsorship. Analytical combustion models developed at JPL will provide propulsion system design guides.

Aircraft Engine Efficiency

Research was completed on a hydrogen enrichment concept developed at JPL with two contractors—Avco Lycoming and Beech Aircraft Corporation. Results showed 20% reduction in fuel consumption by thinning fuel with hydrogen and advancing the spark. Reductions in carbon monoxide and unburnt hydrocarbon emissions were also noted.

NASA Standard Transponder

Standard transponders designed for use on all future NASA earth satellite and deep space missions have been microminiaturized, reducing parts and interconnections. This will mean substantial reductions in weight and volume, power consumption, and stability. The Seasat project will use two transponders.

Space Navigation

The increase in complexity of space missions has caused a corresponding increase in stringency of navigational requirements and produced advances in measurement, orbit determination, maneuver strategy, and ephemeris techniques. Orbiters and landers can now be targeted to Mars with the same accuracy as missions to the moon. The delivery accuracy to distant targets has improved and encounter communications distances have increased, both by a factor of 750 in a decade. Optical navigation using two ground stations came of age with the Viking Mars mission (1976), when the navigation system delivered the two orbiters to accuracies of 30 kilometers. The two-station data modes will be used for Voyager approaches to Saturn.

The feasibility of differential very-long-baseline interferometry for navigation is set for demonstration during the Voyager approaches to Jupiter. Development of the Autonomous Guidance and Navigation Systems planned for missions of the 1980s was begun. A demonstration of a preliminary version is planned for JOP encounter.

Thin-Film Reflectors for Space

Future space programs may require very large areas of reflective surfaces to (1) gather solar energy for power generation; (2) control solar and infrared radiation for large vehicle temperature regulation; and (3) utilize solar pressure for vehicle attitude and orbit control.

Thin-plastic-film technology developed for the solar sail in the past year will have a major impact on the feasibility and implementation of these applications. The sail program reduced substantially the minimum gage of film available in large quantities and suitable for the thermal and radiation environment of space. JPL-directed research verified that the mechanical, thermal, and radiation characteristics are retained in ultrathin film produced by chemical etching, and the film can be coated and bonded and yet retain mechanical integrity for practical handling, assembly, stowage, and deployment.

Surface Chemical Diagnostics

The chemical composition and structure of surfaces and semiconductor interfaces are now diagnosed by a commercial x-ray photoelectron spectrometer modified to provide clear-cut chemical data. New sample preparation, instrumental, and data reduction techniques were developed, along with hardware, software, and etch profiling. These studies are leading to an increased understanding of performance and long-term reliability of integrated circuits.

Solid-State Star Tracker

A flight demonstration model of a solid-state star tracker was built, tested, and delivered to Ames Research Center. The star tracker has been successfully integrated with the attitude control system of a balloon-borne infrared telescope payload.

Linking a microprocessor and a charge-coupled device to the task of multiple star detection and high-accuracy tracking, the star tracker will be able to follow 10 stars simultaneously to an accuracy of better than 10 arc seconds. The entire sequence of operations is controlled by a computerized program of instructions carried out by the microprocessor.

Spacecraft Attitude Control

The Hybrid Programmable Attitude Control Electronics (HYPACE) system was designed to interact with the redundant backup elements of the Voyager Attitude Control System (ACS). Fault detection and correction capability were programmed into the HYPACE flight program. This enables automatic failure sensing at several levels up to the point where a complete processor and memory switch can be made. The processors and memories are always reprogrammable from the ground.

The use of an ACS computer for planetary missions required a special design that minimized weight and power. Voyager is the first planetary mission application. Complete autonomy was a significant requirement because of extended periods of no tracking and the great distances that result in hours of ground command turn-around time. The hardware/software fault-tolerant

philosophy applied to Voyager has established a precedent for future planetary missions.

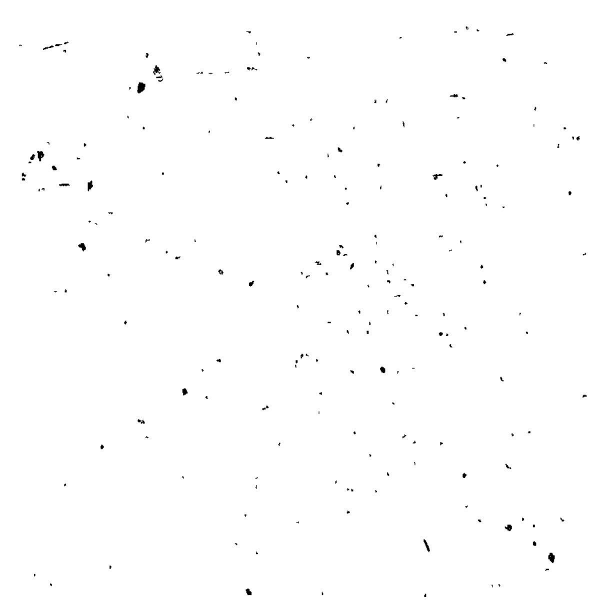
Fire Retardant Polymers

To lessen the smoke toxicity hazard of polymeric materials involved in aircraft and mass transit fires, commercial materials were experimentally modified by the addition of noncombustible fillers that release large amounts of nontoxic vapor, such as water, when heated. About 200 compounds were prepared and tested, and two of these have been selected for further applications testing. One is an epoxy-fiberglass panel material for aircraft interiors, the other an elastomeric material for wire insulation. Both contain over 50% magnesium hydroxide, which releases about one third of its weight as water when heated.

In National Bureau of Standards smoke chamber tests, the experimental panel material produces 70% less smoke than unfilled polymer. Filled elastomer for wire insulation produces negligible smoke even after 5 minutes of thermal exposure. The results indicate that smoke levels can be achieved far below the maximums proposed as new standards in aircraft and mass transit vehicles.

User Program Development

The objectives of User Program Development activities are to identify scientific themes important to the future—both space and nonspace—and to develop Laboratory leadership in the requisite fields. Scientific results in 1977 included a broadening variety of earth applications.



Graphic representation of ocean wave patterns during a hurricane, based on data taken with JPL-developed imaging radar.

Wave Patterns Under Hurricanes

Observations of ocean wave patterns near a hurricane center were negligible until recently. High-altitude aircraft observations with cameras are not generally possible because of extensive cloud cover. Direct surface measurements by ships near the eye are few because of sea conditions, and are limited in coverage.

The JPL imaging radar was flown on a NASA CV-990 over 1976 hurricanes Emmy, Frances, and Gloria, providing high-resolution (~25 meters) imagery of ocean waves regardless of cloud cover, sun illumination, or weather conditions. Wave patterns around and inside the hurricane eye were imaged for the first time.

Fishing Vessel Imaging

In cooperation with NASA/National Space Technology Laboratory (NSTL) and the Coast Guard, a preliminary test of synthetic aperture imaging radar was attempted to locate and identify fishing vessels on the open ocean. In a flight experiment over the Bering Sea, all vessels in the area were detected and imaged by the radar. It was concluded that the ocean background can be reduced to simplify the detectability of the vessels. While digital analysis problems remain, it appears that the method has considerable promise.

Polar Ice Mapping

Four airborne radar observation missions were conducted over Arctic areas to determine the capability of the radar to (1) image ice-covered polar regions, (2) identify navigable leads with open water or thin layers of ice, and (3) determine the breakup rate of the ice cover. The missions were flown during all four seasons of the year. Mosaics were obtained and analyzed. Open waters in the polar sea ice pack are generally smoother than the surrounding ice and image as much darker tones.

Two sets of data, consisting of 22 flight lines over the frozen Beaufort Sea north of Alaska, were mosaicked, digitized, and processed using the JPL Image Processing Laboratory (IPL) systems. With these quick and accurate techniques, it is possible to determine the percentage of open water and movement and rotation of the ice pack. This work has application in polar ship navigation and evaluation of the heat exchange in the polar regions.

Algorithms were also developed to determine the linear and rotational motion of ice flows and the ice pack. Ice motion was measured during the fall season for a 2-week period. This type of work has direct implications in determining the circulation and global motion of the polar cap and Arctic Ocean.

ARIES Sea Measuring

A JPL-developed very-long-baseline-interferometry precision geodetic system called ARIES (Astronomical Radio Interferometric Earth Surveying) is being used by the National Geodetic Survey to resolve discrepancies in sea level determination. Data reduction and analysis of measurements of the sea slope between San Francisco and La Jolla (which shows a discrepancy of 60 centimeters) are currently underway. The ARIES 9-meter station completed measurements between Malibu and Palos Verdes, using the 40-meter telescope of the Caltech Owens Valley Radio Observatory as a base station.

Geological Applications

The objective of the JPL Geological Applications Program is to determine new wavelength bands for future earth resources satellites. It was found that adding a seventh band to the thematic mapper on Landsat-D, centered at about 2.2 microns, will almost double the anticipated accuracy in separating altered from unaltered rocks. With the recommended seventh band, Landsat-D should produce more accurate maps of alteration patterns and open up a new capability in the mineral field.

Earth Resources

Research on sensor simulation and data management procedures promises to improve the accuracy and utility of Landsat follow-on information for land resource inventory applications An analysis of the impact of the Landsat-D Thematic Mapper spatial and spectral resolutions on classification accuracies for urban regions shows that marked improvement can be anticipated.

A computer software system also was developed to integrate Landsat imagery into the mainstream of computer processing, starting with Landsat-C. The new software will enable agencies to obtain tabulations of land cover change and effectively monitor land resources for the first time.

Earth Stratosphere Study

The JPL Michelson infrared interferometer aboard a balloon-borne gondola 39 kilometers above Australia simultaneously measured the vertical concentration profiles of hydrofluorines and hydrochlorides. Knowledge of the abundances and distributions of these two gases in the stratosphere is needed to test hypotheses regarding the effects of chlorofluoromethanes on the earth's ozone layer

Moon Laser Ranging

JPL continued to provide predictions and reduce data for the laser ranging pulses beamed by the McDonald and Haleakela observatories to the retroreflectors placed on the moon by Apollo astronauts. This experiment has resolved facts regarding earth–moon rotation and dynamics. The geocentric coordinates of the McDonald observatory are now known to an accuracy of 1 meter—making the observatory one of the most precise points on the earth's surface—while the locations of the retroreflectors are known to within 20 meters. The mass of the earth has been determined to one part in 4 million. The lunar ephemeris and rotations (physical librations) also are being steadily improved.

Lunar Surface Chemistry

An expanded analysis of thorium concentrations in the lunar surface as measured by the Apollo gamma-ray spectrometer has yielded new information on the distribution of radioactivity. A negative correlation between crustal thickness and thorium surface concentration in lunar highlands has been found. The linkage between the surface and the underlying crust indicates that the initial character of the surface has not changed much since early lunar history.

Lunar Gravity Field

Analysis of Lunar Orbiter and Apollo tracking data for a better lunar gravity model has produced more precise figures for both nearside and farside ringed basins. The isostatic states of lunar features such as mascons, mountain ranges, and 100-kilometer-diameter craters are being investigated. To date, Mare Orientale, the Apennine Mountains, and 10 large craters have been evaluated.

Asteroid Evolution

A study of the origin and evolution of asteroids and meteoroids identified debris from 104 collision events in the asteroid belt. A resonance theory was developed to explain how meteorites move out of the asteroid belt and into earth's vicinity. Orbital studies also were made to support Palomar Observatory's search for unusual asteroids.

Microwave Spectroscopy

The first narrowband molecular line was detected in the microwave spectrum of a planet by JPL and Aerospace Corporation scientists. This was an absorption line of carbon monoxide in the atmospheres of Venus and Mars, and subsequent observations showed that line intensity and shape changed significantly over a 3-month observational period. These findings provide the first empirical evidence to support global circulation models in which dayside-produced atmospheric constituents are circulated to the nightside of a planet.

Global data have been obtained from the JPL Scanning Microwave Spectrometer (SCAMS) on the NIMBUS-6 earth observatory satellite. SCAMS is the first spacecraft instrument to combine microwave spectroscopy with imaging, proving that microwaves can penetrate and map subsurface structures under dry ice and snow and also map atmospheric temperature profiles and distributions of atmospheric water and water vapor.

Solar Physics

Analytical techniques were developed to determine the first solar wind velocity profile to within 1.7 solar radii from the sun, following tests with the radio signal data from Helios 1 and 2. These techniques will be useful in obtaining information from future missions very near the sun.

Interplanetary Magnetic Field

Observations of the interplanetary magnetic field by Pioneer 11 established the existence of a thin current sheet surrounding the sun and extending throughout the solar system into distant space. Studies show that this sheet effectively divides interplanetary space into two hemispheres containing oppositely directed magnetic fields.

The current sheet is inclined at an angle of about 15 degrees relative to the solar equator so that, as the sun rotates, spacecraft in or near the ecliptic will lie alternately above and below the current sheet. This effect is responsible for the observed sector structure of the interplanetary field, with polarity alternating from outward to inward during a solar rotation (27 days). These findings may spur further studies of solar magnetic fields and the propagation of cosmic rays.

Io's Sodium Cloud

The first direct pictures of Io's extended sodium cloud were obtained at JPL's Table Mountain Observatory. The images of the Jupiter moon were recorded as digital intensity levels via a Silicon Imaging Photometer System (SIPS) using a silicon vidicon tube detector. The detector was mounted on the Coude spectrograph of the 61-centimeter (24 inch) telescope.

The images revealed that the vast cloud extends some 100,000 kilometers and is somewhat banana shaped, with more sodium preceding Io in its orbit than following. Thus far, a model involving escape of sodium from a specific localized area on Io provides the best explanation of observed intensity distributions.

Astronomy – Cosmology and Relativity

Solutions for the motion of the planets were obtained such that the precession of the perihelion of Mercury can be predicted to within four hundredths of a second per century. The Einstein general theory of relativity continues to be consistent with observations. Solar gravity studies implied that the rotation rate of the sun is more rapid internally than what is observed on its surface.

Mars Moon Study

Viking Orbiter photographs of Phobos, the inner moon of Mars, revealed a curious series of striations or grooves over much of the surface.

An analysis by JPL and Cornell University investigators suggests that the grooves (or graben) may have resulted from tidal stress as the moon's orbit evolves inwards from the pull of the planet.

Planetology

Radar images and topographic maps of Venus were produced from data obtained at the Goldstone Deep Space Network tracking station. Data for approximately 7% of the planet have been reduced to produce the only existing topographic maps and the highest-resolution imagery (about 10 kilometers) yet made available. Findings indicate that there may be regions of large impact craters on Venus and at least one large shield volcano (Beta) that rivals Olympus Mons on Mars in size.

Striations on Martian satellite Phobos discernible in Viking image indicate that the satellite may be breaking up as a result of a combination of tidal forces and impacts.

TRACKING AND DATA ACQUISITION

During the first part of the period covered by this report, the Deep Space Network (DSN), developed, implemented, and operated by the JPL Tracking and Data Acquisition Office (TDA), successfully supported the Viking missions to Mars using the network capability that had been reached before the two planetary encounters. At the end of the period, the Voyager launches to Jupiter and Saturn were supported at a new capability plateau attained with the Mark III Data Subsystems (MDS) currently completing implementation. Challenges in the form of requirements to enhance the capabilities for support of Voyager encounters with the two planets were met when the DSN completed the necessary design prior to launch. Implementation for tracking of Pioneer Venus entry probes neared completion. Significant milestones in technology demonstrations and in facility plans for supporting the planetary missions of the 1980s and new end users of TDA service were achieved as well.

Mission operations personnel at work in the Space Flight Operations Facility tracking spacecraft in flight.

Operations

A record 14 active spacecraft were tracked by the DSN during the period. Two Viking Mars orbiters and two landers began operations. Helios 1 completed five perihelion passages, and Helios 2 completed three. Pioneer 11 was tracked beyond 1 billion kilometers on its way to Saturn. Pioneer 10 was tracked beyond 2 billion kilometers on its way out of the solar system. Voyagers 1 and 2 were tracked in the launch and early cruise phases. Pioneer 6 was tracked for the twelfth year since its launch in 1965; Pioneers 7, 8, and 9 also were tracked during events of special interest.

Viking operations generated the most demanding requirements ever placed on the DSN. Two spacecraft in orbit and two landers on the surface required the reception at times of six telemetry streams simultaneously from three spacecraft by a single 64-meter antenna. By the end of the prime mission in November 1976, the DSN had provided more than 16,000 hours of tracking support, transmitted more than 72,000 commands, and delivered 99.98% of all the data received at the stations. Throughout the mission, continuous high-performance telecommunications links were maintained from earth to each spacecraft over more than 320 million kilometers. In November 1976, when Mars approached solar conjunction, extreme care and highly skilled use of the DSN ranging equipment throughout the network permitted gathering of data as the radio signals from the spacecraft passed near the surface of the sun. Such signals had never before been successfully received after passing so close to the sun's surface. The data collected were crucial to the relativity experiment, in which the verification of Einstein's general theory of relativity was established with the greatest accuracy to date. The experimental uncertainty was reduced to 0.5% from previous levels of 2%. These results were achieved in part by the opportunity to track both landed and orbiting spacecraft and in part by two significant new DSN capabilities: the subnet of three 64-meter antennas was newly equipped with an X-band (3.55-centimeter) receiving capability and a new dual-frequency (X- and S-band) ranging system. The dual-frequency ranging data permitted calibration of the effects of charged particles on the radio signals. These data represent the most extensive and direct measurements of electron density in the solar corona yet acquired.

Ranging data from landers and orbiters also supported planetology and celestial mechanics experiments with a wealth of information on Martian pole movement, spin rate, gravitational fields, and ephemerides. Special open-loop receivers, operating at both X- and S-band, observed orbiter occultations and provided data on the Martian atmosphere, ionosphere, and topography. Additional special equipment (calibrated receivers, hydrogen masers, and a wideband recording system) was installed at the 64-meter stations in Australia and at Goldstone. This equipment was used for a very-long-baseline-interferometry (VLBI) experiment; the antenna was pointed alternately, for short periods,

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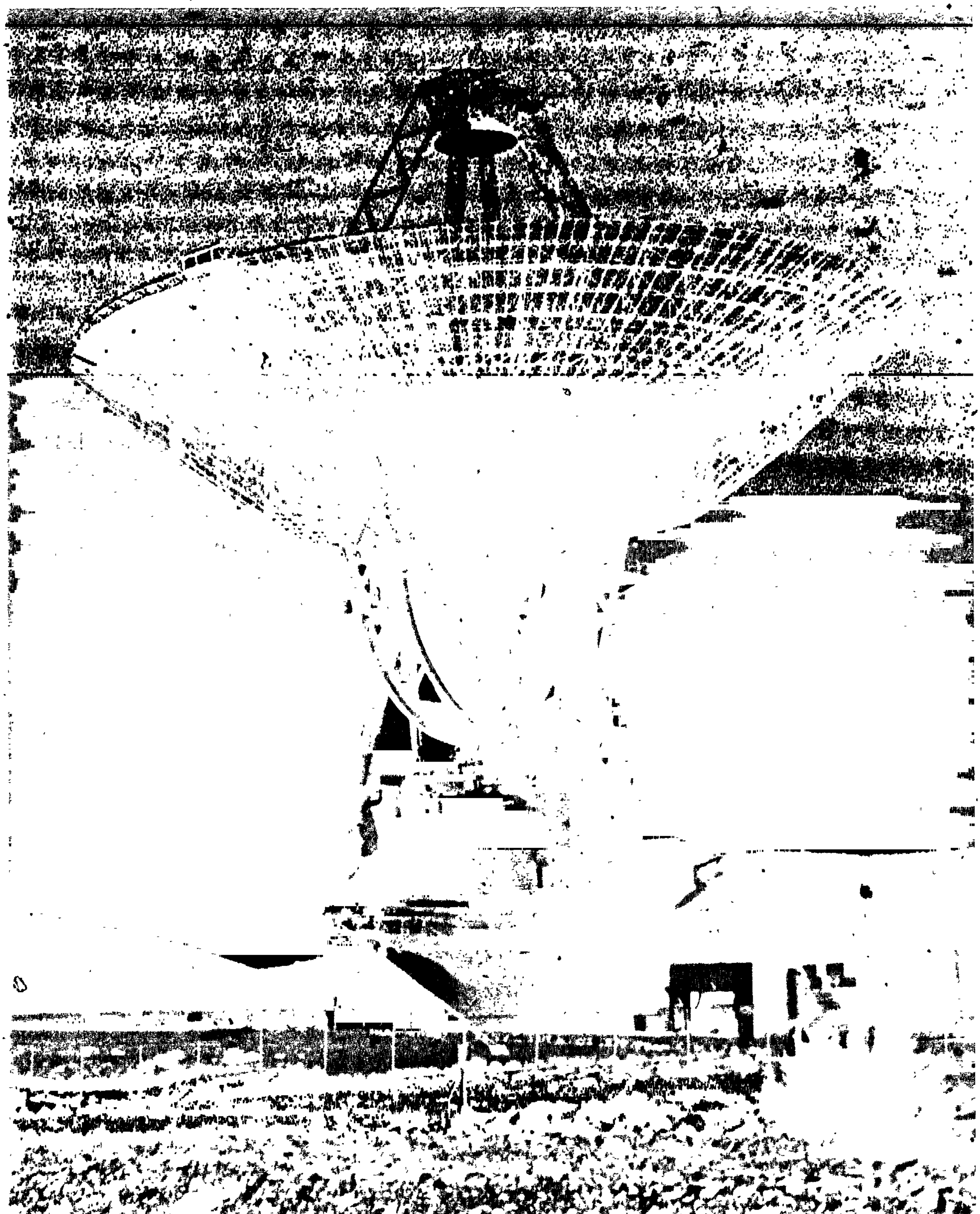


The 64-meter antenna at the Goldstone tracking station was used for many scientific experiments in addition to its spacecraft tracking function. Among these was a test of Einstein's general theory of relativity.

at a Viking orbiter and various quasars. The data were used to determine more precisely the relative positions of the earth, Mars, and the spacecraft.

Phased into the operations support of the ongoing missions were the preparations of the DSN for launch and cruise of the Voyager spacecraft. The preparations were keyed to implementation of the MDS at the prime 26-meter antenna station subnet for Voyager and the 64-meter antenna at Goldstone. The new capability supported the launch and early cruise of the two Voyager spacecraft with no significant difficulties and provided solid support to the Project in its trouble-shooting of early spacecraft problems.

Important progress was made in the prediction and avoidance of radio frequency interference (RFI), a problem of increasing significance to the planetary program. Better techniques were developed to predict interference to tracking deep space probes from earth-orbiting satellites of NASA, the Department of Defense, and the European and Japanese space agencies. Whenever necessary, procedures were developed and used to minimize RFI by turning off an interfering ground transmitter or satellite. Even with close coordination with military agencies that routinely conduct electronic countermeasures, bombing, and other exercises in the vicinity of the complex, RFI at Goldstone continued unexplained.

An important first step was taken in the comparison of VLBI techniques with laser techniques for precise position measurements at continental distances. An intercomparison project was established, and the first three-station demonstration was conducted at Goldstone. The purpose of this initial effort was to establish reliable station operation and identify problems in preparation for transcontinental measurements. The VLBI measurements agree with conventional surveys to within 15 centimeters.

NASA and non-NASA radio astronomers continued to use DSN facilities, primarily at Goldstone. The Goldstone 64-meter station provided nearly 50% of the total support. The experiments supported included VLBI observations, radar observations of several planets and other objects in the solar system, and radio metric observations of Jupiter and the moon. The DSN stations overseas are available to radio astronomers of the host countries for conducting radio astronomy observations. In the past year, use of these facilities for this type of work has shown a significant increase.

Facility Modernization

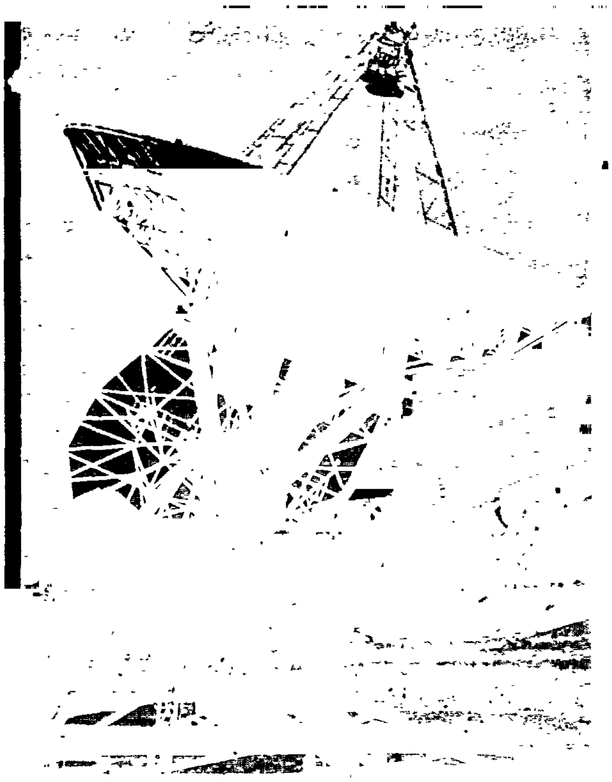
A major effort in facility modernization was largely accomplished in 1977. The Mark III Data Subsystem project replaced aging equipment with modern minicomputers. The older computers and other equipment had been in service more than a dozen years and had become increasingly expensive to operate and maintain. In each of six of the nine tracking stations and in the test facilities at JPL and Cape Canaveral, seven to ten modern minicomputers replaced the older computers. The new data processing equipment comprises the major part of the telemetry, command, and communications subsystems. Therefore, in addition to upgrading older capabilities, the subsystems meet new requirements such as high-rate coded telemetry data handling and increased reliability for long-term missions such as Voyager and greater flexibility for a variety of future missions.

An outstanding feature of the MDS is that it accomplishes its task with a marked cost savings over older methods. Because of the increased emphasis and dependence on computer software, the DSN also developed new software methodology and standard practices for its development and control. This methodology incorporates understood engineering processes, using structured programming, for going from requirements to the delivered computer program. The standard practices provide the appropriate control of the implementation effort. This approach is one result of an intense effort in the DSN to increase productivity and cost effectiveness and enhance service to the flight projects.

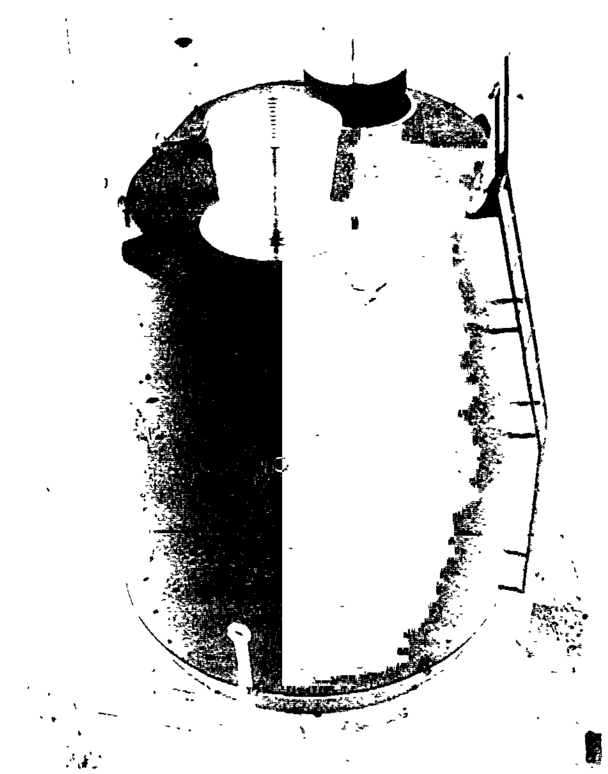
The installation of the minicomputers was an extensive effort, involving replacement of approximately 20% of the electronic equipment at each station. Each station was therefore removed from service for slightly more than 2 months. The installations were phased to support ongoing flight missions without interruption. Other work in preparation for the Voyager Saturn encounter also was accomplished during the MDS upgrade.

Work started on a project to increase the diameters of three 26-meter antennas to 34 meters, the first to be completed by 1978. In addition, X-band receiving capability is to be added to these stations so that when Voyager encounters Saturn, the signal from a 34-meter antenna can be combined with that of the 64-meter antenna at the same longitude. The additional sensitivity is intended to allow reception of television pictures in real time at the encounter.

Two difficult design problems were solved in the 26-meter antenna project. One was to design a system to lift the 406,000-kilogram tracking antenna to accommodate the larger diameter. The scheme adopted uses a heavy lift frame and a system of hydraulic jacks and manifolds with cribbing to enable the entire antenna to be lifted 3 meters with an accuracy of 0.13 millimeter for both horizontal and



Lift frame and hydraulic jacks raise a 26-meter antenna in preparation for modifications. The 406,000-kilogram antenna can be lifted 3 meters with an accuracy of 0.3 millimeter.



Dual-frequency S/X-band feed cone with waveguide horns is part of new equipment for modified 26-meter antenna.

vertical placement. The other design problem solved was the addition of X-band capability to a 26-meter antenna without excessive degradation of the S-band frequency performance. JPL engineers developed a numerical RF scattering technique for the optimum placement and shape of secondary reflectors and the feed assembly to minimize the RF blockage and spillover. These challenges, along with others, have been met for the design of the S-X Band Conversion Project, which is now in the procurement and fabrication process.

New receivers and magnetic tape recorders were designed to support the Pioneer Venus entry probe experiment. This equipment allows the simultaneous reception of the signals from one large entry probe and three small ones. Using very-long-baseline-interferometry techniques by combining signals from different stations, the equipment will provide for measurement of the Venus wind effects on the probes.

Navigation ranging accuracy requirements for Voyager were more stringent than for Viking by a factor of three. Early Viking ranging indicated that a range accuracy of 10 meters could be met by normal ranging techniques, but the Voyager requirement for near-simultaneous two-station ranging was 4.5 meters. Demonstrations were conducted in early 1977 which showed that 4.5-meter ranging accuracy could be met by a series of very rigorous calibration improvements.

The Search for Extraterrestrial Intelligence (SETI) Project has completed a year of fruitful planning. Considerable activity has led to a coherent observational plan and firm concepts for the vital elements of the SETI field system. The goal is a coordinated sky search for signals from outside the solar system, with valuable radio astronomy data as a byproduct.

Advanced Systems

DSN Advanced Systems continued development of new capabilities to support future projects. Although the operational tracking system used for Viking is capable of a navigation accuracy at Mars of 100 kilometers, it does not, as has been pointed out, meet Voyager requirements at Saturn. During the Viking extended mission, a new technique demonstrated the required improvement by reducing the single-station relative range error to 4 meters. The technique is dependent on the use of a hydrogen maser frequency standard and two-station differenced range

measurements. The hydrogen maser provided an improvement of two orders of magnitude in frequency stability over the rubidium frequency standards used earlier. The differenced range technique improves accuracy by comparing data taken from two stations as nearly simultaneously as possible.

Another technique, dual spacecraft tracking, demonstrated a seven-fold increase in navigation accuracy. By tracking two spacecraft (Vikings 1 and 2), only one having a well determined orbit, the orbit of the other was established relative to the first with great accuracy. The dual-frequency calibration technique, made possible by the addition of the X-band receiving capability, contributed a factor of three to these improvements. The unprecedented accuracy achieved in the Viking relativity experiment was made possible by use of the Goldstone 64-meter antenna experimental Advanced Systems ranging equipment. In addition to providing radio metric data, it also afforded helpful technology guidance that permitted the planetary ranging assemblies at the 64-meter antenna stations in Spain and Australia to track beyond their normal capabilities. The range measurements were made with a precision of 10 nanoseconds out of a round-trip light time of 2500 seconds, or one part in 4×10^{12}. This is one of the most precise distance measurements ever made by man.

The development of higher-accuracy tracking by two-station techniques also continued with the improvement of VLBI capabilities. Six necessary key system elements were developed in prototype form: 40-megahertz receivers, hydrogen masers, receiver phase calibrators, dual-frequency charged particle calibration algorithms, water vapor radiometers, and a data correlator. Completion of the Caltech–JPL 4-megabit-per-second correlator provides users on the West Coast with a means of reducing VLBI data locally. Previously, these data could be reduced only at the National Radio Astronomy Observatory facility at Charlottesville, Virginia. NASA and National Science Foundation funding were combined to create a center for VLBI correlator expertise at Caltech and JPL, providing a national radio astronomy facility. The VLBI catalog of known compact radio sources was expanded to more than 300 objects, two thirds of which were identified by JPL observations between Goldstone and Spain.

High-power transmitter development continued at both S- and X-band to improve reliability. Radar observations of Venus, the rings of Saturn, and the Jovian satellite Callisto were made employing the improved capabilities. Extensive S-band radar mapping of Venus was accomplished using three Goldstone stations simultaneously in an interferometric mode.

Several conceptual studies and designs were conducted to provide the foundation for future DSN capabilities. An Orbiting Deep Space Relay Station (ODSRS) concept was studied to determine the feasibility of providing 24-hour, long-baseline spacecraft coverage with a single earth-orbiting antenna. This concept may be a cost-effective way to increase data rates and antenna gains with higher frequencies and larger apertures than are possible on earth.

Two concepts were studied to reduce operational costs: Bent Pipe and spacecraft surveillance. The Bent Pipe concept would centralize the telemetry and command processing equipment, using commercial earth satellite communication links. The second cost reduction concept would provide small instruments to monitor a spacecraft during cruise without requiring large tracking stations.

Two new radio metric navigation concepts were developed with a goal to improve the DSN planetary navigation capability by one order of magnitude. Differential spacecraft–radio source VLBI, the process of measuring the angle between a spacecraft and a natural radio source using VLBI, will enable navigation to a Jupiter satellite with relative accuracies of 50 kilometers. A second concept with the same accuracy potential uses three instruments to measure the one-way range to a spacecraft and to determine its right ascension and declination.

Finally, a 300-megahertz, 1-million-line digital spectrum analyzer design was developed. This analyzer will be used with a steerable medium-gain antenna and data processor to monitor and characterize the RF environment at the deep space tracking stations. This technology is needed to keep the DSN operable in a worsening RF environment, and may be useful in SETI and planetary radar.

Space Flight Operations Facility is the control center for all unmanned planetary exploration spacecraft.

CIVIL SYSTEMS

During the past year, the Laboratory's focus on technical problems and applications in the civil sector has strengthened, particularly in the area of energy systems.

The Civil Systems Office was reorganized into three technical program areas: Solar Energy; Coal, Geothermal, and Conservation; and Technology Applications. The field of energy research and development has become the major new program area for JPL, with emphasis on Solar Energy. Growth during the year was most marked in this program, although the other areas displayed lively, varied activity.

Solar Photovoltaic Arrays

The largest single effort in Civil Systems was the Low cost Silicon Solar Array (LSSA) Project. Established in early 1975 under sponsorship of the Energy Research and Development Administration's (ERDA) Division of Solar Energy, the project has a 10-year goal of developing a large national production of silicon solar array modules at greatly reduced prices. The LSSA Project office has issued more than 80 contracts for research, process development, analysis, and production to a variety of firms and university laboratories. Work within JPL included analytical and economic studies, process studies and evaluations, and performance and environmental testing of solar modules.

Significant developments were:

(1) A computer model of the solar array industry, a series of costing standards, and a cost estimate program permitting comparison of technological options.

(2) Establishment of a laboratory to produce high purity silicon plus contractor development of various alternative processes.

(3) Evaluation of contractor efforts in ingot, ribbon, and sheet growth of solar cell blanks. Several successful developments toward novel mass production processes of cell material, notably in silicon ribbon growth, were achieved.

(4) Progress in life prediction methodology seeking a 20-year field life for arrays, and selection of encapsulation material candidates including glass, acrylics, and fluorocarbon film materials. (Advanced processes studied by contractors included electrostatic bonding of silicon cells to glass and ion plating of the cells.)

(5) Start of a new research effort to define the effects of fabrication processes on silicon sheet properties and solar cell performance.

(6) Integration of three independent technology assessments of solar array manufacturing.

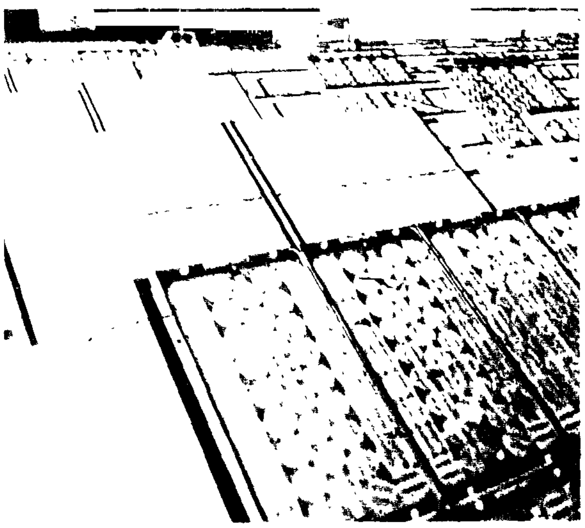
(7) Evaluation and testing of the first deliveries of solar cell modules of advanced and experimental design, contracted for by JPL.

A three-site field testing program was set up at JPL in Pasadena, Table Mountain, and Goldstone. An automated system for long-term performance data is part of the JPL Pasadena test operation.

Engineering advances included development of a comprehensive photovoltaic module specification based on user needs and studies of potential module design.

Many tests resulted in the definition of electrical and mechanical performances, efficiency requirements, and the effects of operating temperatures and environmental conditions.

From July 1976 through September 1977, the LSSA project procured over 132 kilowatts (peak capacity) of solar array modules for testing and the ERDA applications program, for a total to date of 148 kilowatts. This effort has both stimulated industry growth and demonstrated progress in price reduction, two major goals of the project.



Solar photovoltaic cells for terrestrial use undergo tests in special facility atop the mesa above JPL

Solar Heating

Project SAGE (Solar Assisted Gas Energy), sponsored by the National Science Foundation, the Southern California Gas Company, and the Federal Energy Administration, and conducted collaboratively by the Laboratory and the Gas Company, added a second large demonstration of residential water heating. The system was installed in an apartment complex at

Upland, California, following a successful year of the first operating system at El Toro. Test data from the two systems indicate substantial saving of gas fuel in the Southern California area but, without consideration of solar energy tax incentives and at the present level of natural gas prices, do not yet demonstrate a clear economic advantage.

A study of solar energy use in buildings was made for the California Energy Commission. It weighed technical, economic, and institutional factors and analyzed policy implications. The study concluded that institutional factors would require the greatest attention for solar applications to grow in California.

Solar Thermal Power

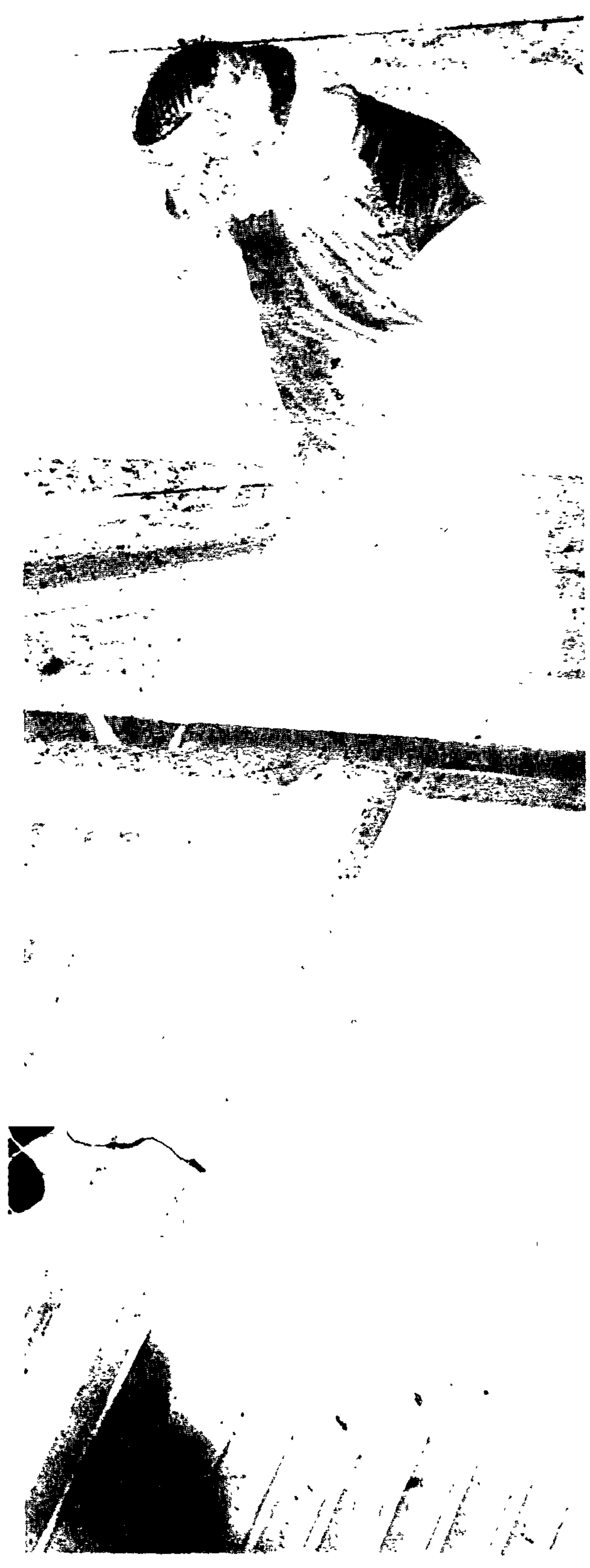
A complex effort in thermal power systems for ERDA's Division of Solar Energy has progressed with research and technology development for point-focusing distributed systems. A small power-systems application project is developing conceptual studies for a small-community (1-megawatt) solar thermal-electric power system to be in operation by 1985. A technology project will develop later-generation systems, with technical work divided among JPL, NASA Lewis Research Center, and contractors. A research and development project is coordinating contractor and JPL research efforts at a more fundamental level to provide a basis for future solar thermal technology.

Another solar-thermal experiment for NASA's Office of Energy Programs is testing a kilowatt-scale so' Stirling system. This uses a 2.9-meter (9½-foot) parabolic reflector, a JPL-built energy receiver, and a Stirling engine with a linear alternator. Initial evaluation of the concentrator and receiver was made in mid-1977 at Table Mountain, with energy collection rates of close to 3.5 kilowatts and receiver temperatures over 1100°F.

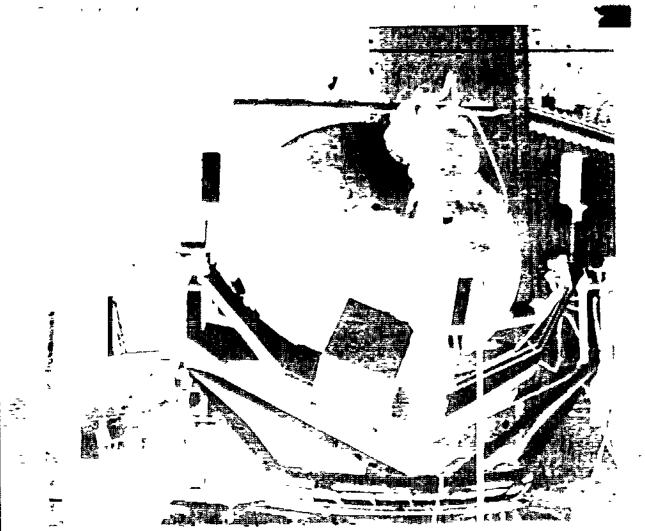
Other work included ERDA-sponsored testing of a JPL-designed V-trough collector, whose lightweight design incorporates a two-step adjustment for seasonal changes in the solar latitude, and which showed thermal collection efficiencies of 20 to 35% at temperatures up to about 132°C. A related study for ERDA examined the thermal storage potential of steel ingots at temperatures from 316 to 538°C.

Utility Systems

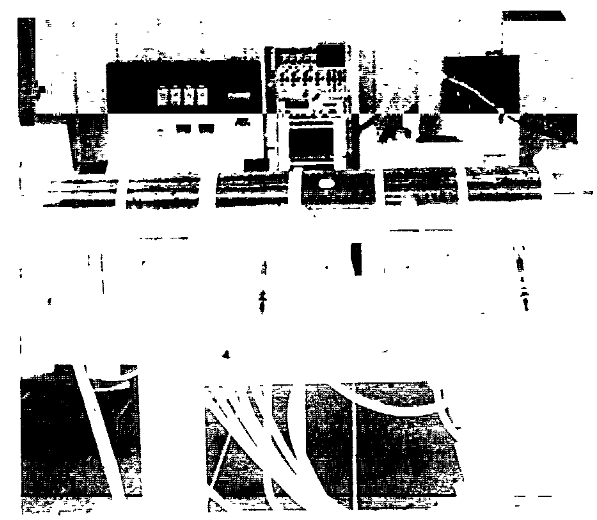
A utility systems program was begun under ERDA support to study problems of fuel processing, cogeneration, utility communications, lightning impacts, and hydrogen energy storage. The study of heat and electri-



V-trough collector offers two-step adjustment for seasonal changes in solar latitude, increasing the efficiency of units intended for heating and cooling buildings.



Kilowatt-scale solar Stirling system with parabolic reflector being used in solar-thermal experiment.



Coal extruder is part of coal processing and mining study being conducted for Bureau of Mines.

Hybrid-powered Volkswagen minibus undergoes tests in program to improve fuel savings and reduce air pollution.

city cogeneration for industry was completed for the California Energy Commission.

Geothermal Energy

A survey of geothermal energy resources in California was produced for the State's Energy Commission, as well as a requirements analysis for accelerated development of geothermal energy in the state, supported by ERDA and the Commission. The purpose was to outline how geothermal fields might play a major energy role in the state after 1985.

Technical work for ERDA centers on a geothermal powerplant concept developed by a California inventor, employing a helical-screw expander design to cope with dirty geothermal sources. A 1250-kilovolt-ampere power plant, with JPL instrumentation and auxiliary equipment, is being readied for testing near Milford, Utah.

Coal Processing and Mining

Several studies in coal mining, processing, and handling were conducted for the Bureau of Mines and other sponsors. One promising application for production of fluid fuels from coal in pressurized reactors involves use of heat and pressure to plasticize coal, which may then be extruded or pumped. The extruder device demonstrated long-run capability for two types of coal.

Under development is a desulfurization process using chlorination to oxidize organic and inorganic sulfur in coal to sulfate compounds removable by a simple water wash. The process, which removes over 70% of organic sulfur, received contractual support from the U.S. Bureau of Mines. Preliminary cost projections suggest an attractive low cost that is competitive with other proposed coal desulfurization processes.

Also for the Bureau of Mines, an advanced coal extraction systems definition project produced technical and economic studies, including a life cycle economic model of underground coal mining. An evaluation of borehole hydraulic coal mining considered technical, economic, environmental, health/safety, and geologic/topographic factors.

Transportation

Continuing its search for cleaner, more efficient automotive engines, JPL initiated an Electric and Hybrid Vehicles Project as part of NASA's support of ERDA's transportation energy conservation activity, and continued its work in system studies and instrumentation development.

Begun in the spring of 1977, the project assumed management of development contracts and, with Lewis Research Center, conducted two technical studies. One was a survey of electric vehicles in service in North America; the other involved testing two electric and one hybrid vehicle.

The survey evaluated about 1000 electric automobiles and trucks. Ten manufacturers (mostly adaptors of conventionally powered vehicles) operate in an unstable market with marginal service facilities; initial and service costs are high, but the energy cost is attractive. A few fleets exist, notably in the U.S. Postal Service, which has imported vans designed for electric propulsion rather than adapted. Vehicle systems, energy systems, and component development, as well as production and service development, were seen as essential to the expansion of electric-powered vehicle use.

Vehicle testing produced data to support analysis of the energy flow from fuel tank to wheels and/or from battery to wheels, and from wall plug to battery, and to support construction of a mathematical model of the vehicle system. Tests were conducted on the JPL dynamometer, the road, and track. Vehicles tested were a Volkswagen hybrid system van, a Fiat electrified van, and the Rippel electric power modification of a Datsun sedan with regenerative braking.

Another transportation study evaluated alternate concepts for underground rapid transit. Performed for the Department of Transportation (DOT), the review considered gravity assist for energy conservation, simplified tunnel and station design, propulsion alternatives, and operational controls. Potential reductions in energy use and construction cost were associated with modest technical changes.

Another task performed for DOT was a traffic-monitoring instrumentation and information system which seeks ways of improving efficiency of freeways, highways, and streets and assesses capabilities of existing sensors and data processing techniques. A conceptual design resulting from this study was developed.

Sewage Treatment

An Activated Carbon Treatment System (ACTS), in pilot plant evaluation for 18 months, produces activated carbon from sewage solids and uses the carbon to purify the waste water at a 3,785,000-liter (million-gallon)-per-day plant installed by the Orange County Sanitation District in Huntington Beach, California. The district's conclusions indicate that the system is technically and environmentally satisfactory and economically

competitive. Additional technical work proposed by JPL is still required to support future implementation for larger-scale sewage plants. The ACTS project was co-sponsored by the Environmental Protection Agency, the State of California, and Orange County.

Natural Resources

Two studies of the application of aerospace technology to petroleum industry problems were prepared for NASA, with industry cooperation. A petroleum exploration study covered seismic reflection systems, down-hole acoustic techniques, geological analysis, drilling, remote geochemical sensors, and sea floor imaging. A petroleum production study analyzed problems in determining reservoir characteristics, geologic structure and pressures, steam injection losses, and water sources for injection.

Another resources study analyzed water resource management for hydropower systems, seeking aerospace-derived information system technology. The study developed an applicable information system concept, essential to control and reduce spillage, and made recommendations for remote and surface sensing, modeling, and analysis.

Pollution source chart for Los Angeles County was developed using satellite data, traffic information, and map subdivisions.

An important natural resources activity is land use image processing, originating with satellite (Landsat) data. Emphasis has shifted from simple satellite image processing (such as the discrimination of phases in agriculture or strip mining) toward integration of image and geo-coded statistical data leading to automated functional mapping. This Image Based Information System is an ongoing technology transfer from NASA to the Census Bureau. A typical recent result is the development of a pollution source chart by integrating local traffic zone information and map subdivisions with satellite-derived land use data. Portland, Oregon, and several Southern California areas have been used for this work.

Biomedical Applications

Various technology and systems applications and developments continued in the medical field, in collaboration with the University of Southern California and others. These activities stem from JPL expertise in digital image processing and instrumentation.

Two image processing devices were added to JPL automated karyotyping and arteriogram analysis systems. In each case, a compact minicomputer system was designed to produce a diagnostic-aiding graphic presentation rapidly from a medical image—micrograph, x-ray arteriogram, or coronary angiogram.

A muscle biopsy analysis system, co-sponsored by the Muscular Dystrophy Associations of America and NASA Technology Utilization, produces a display to measure muscle fibers, which will eventually aid physicians in diagnosing and treating muscular and neuromuscular disease.

The coronary angiogram work extended an x-ray system for assessing disease in the femoral artery. The work on the more complex coronary arteries, cosponsored by NASA Life Sciences and the National Institutes of Health (NIH), is expected to improve the system's capability for quantifying atherosclerosis.

Mass spectrometry use for clinical diagnosis involves collaboration with specialists at Caltech, the USC School of Medicine and Children's Hospital, Martin Luther King Hospital, the Baylor and UC San Diego Medical Schools, and the NIH Clinical Chemistry Laboratory. A recent and promising diagnostic device is the electro-optical ion detector which overcomes problems from the analyzer's magnetic field. It converts the ion spectrum of a focal plane mass analyzer into an optical display, using electron multipliers, a phosphor screen, and a vidicon imaging device. Work is continuing on the optical sensor array and overall miniaturization.

OTHER ACTIVITIES

Planning and Review

The Office of Planning and Review functions primarily in a staff and support role to the Director's Office, and is responsible for a variety of administrative, planning, assessment, and review activities.

Planning tasks during the reporting period included a careful review and assessment of NASA's prospective future programs and budget. A somewhat similar examination of ERDA's programs was carried out also, especially in those areas having application to JPL. Assessments of this nature are performed annually to ensure up-to-date background and understanding for use in the formulation and updating of Laboratory goals, objectives, and institutional plans. The JPL Five-Year Plan was restructured to conform to the present Laboratory organization, and fully revised in content in accordance with current policies.

Reviews of institutional characteristics and operations took several forms: A survey was conducted among a representative group of professional employees to sample opinions about the character of the Laboratory, as it seems to be and as it ought to be; a follow-up survey probed further into attitudes relative to risk-taking in its several forms. Initial steps were taken to establish processes aimed at identification and modification or elimination of policies, practices, or procedures that may be redundant or overly bureaucratic. In addition to estimates of the funding and manpower resources required and expected to be available to implement prospective programs, special attention was given to assessing the nature of constraints that may exist in facilities availability, especially in view of the fact that significant new construction in the foreseeable future is unlikely. Among questions dealing with the improvement of formal review processes affecting Laboratory activities, particular attention was devoted to the substance of regularly scheduled reviews for the Director, and to the preparation, coordination, and approval of proposals for new work, both NASA and non-NASA.

The Office maintains Laboratory-wide manpower plans and makes allocations at the program and division levels. NASA's strong interest in matters of manpower utilization remains undiminished, and, in addition to the long-standing ceiling on JPL employees, the agency has adopted new policies with respect to identification and accountability for support-contractor personnel.

Director's Discretionary Fund

The Director's Discretionary Fund (DDF) was established by the NASA-Caltech Memorandum of Understanding (December 1968), and is currently funded at $550,000 annually. The fund provides support for independent research and development in promising fields of science and engineering. It supports seed efforts and encourages collaborative work with faculty and students at Caltech and other universities. Potential for follow-on funding (not DDF), either NASA or non-NASA, is one criterion in evaluating proposals and selecting tasks for DDF support.

A recent survey (January 1976) of DDF task activity since inception showed that about 20% of all tasks have involved co-investigators from Caltech, and further that about 35% of all tasks have involved university participants, either Caltech or other. In terms of follow-on interest, the survey indicated that 25% of the tasks had obtained follow-on funding, and that the total of such funding was nearly six times the total of DDF funds expended on all tasks, with considerably more supplementary support in prospect.

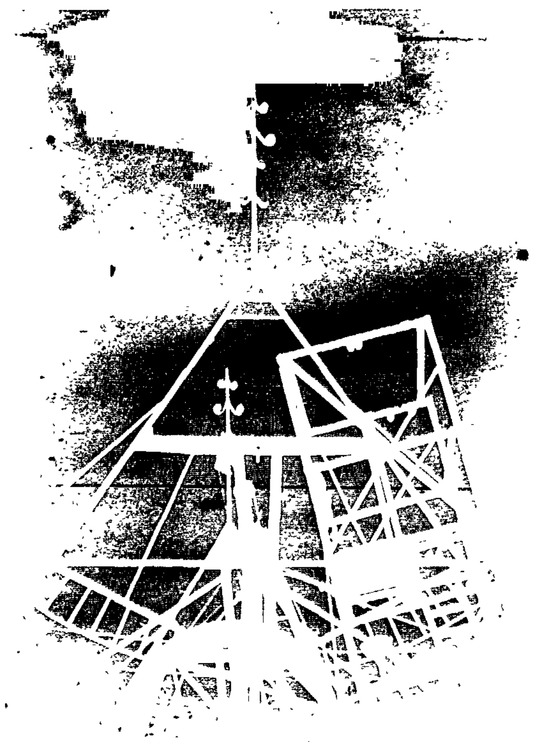
DDF funding is usually in the range of $15,000 to $40,000 per task. In Fiscal Year 1977, 17 tasks were funded from a total of 70 proposals submitted.

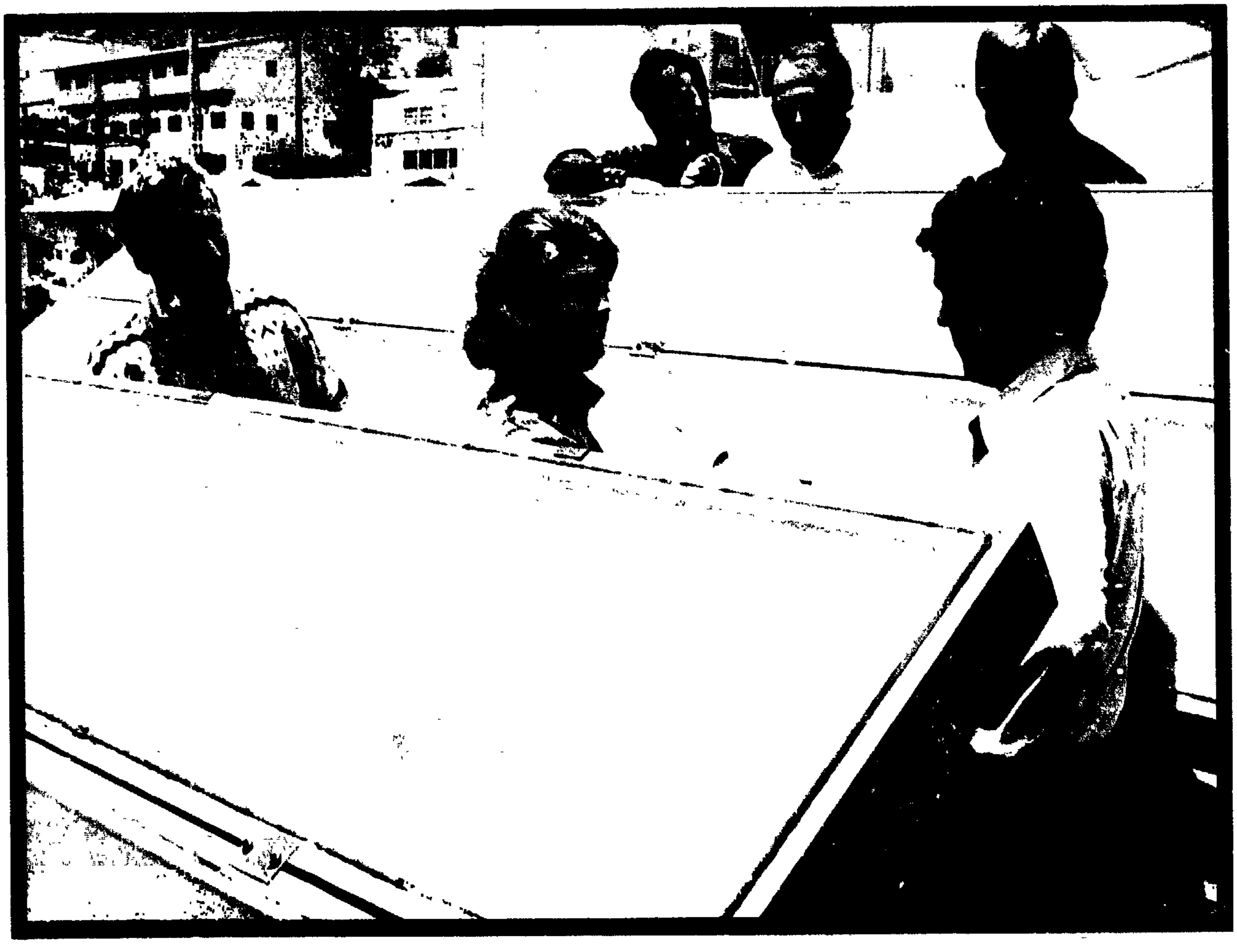
Quality Assurance and Reliability

Quality assurance and reliability activities support all levels of technical, project, and Laboratory management in guarding against defects and failures of flight and nonflight hardware and software. About 2% of the Laboratory manpower and dollars are directly involved. The reporting period was one of intense activity in supporting the final stages of spacecraft development and launch preparations for Voyager. Support of Seasat-A, which is scheduled for launch in May 1978, is in a similar phase and added considerably to the workload. Flight instrument developments for other NASA projects (non-JPL), and new equipment for installation in the Deep Space Network also required important efforts during the year.

Administrative Divisions

Funding for JPL's ongoing tasks and new efforts in research and development amounted to $69,000,000 during the 3-month transition period for converting the Government's fiscal-year start from July 1 to October 1, 1976, and to $275,000,000 during FY'77—the highest in the history of the Laboratory. Civil Systems



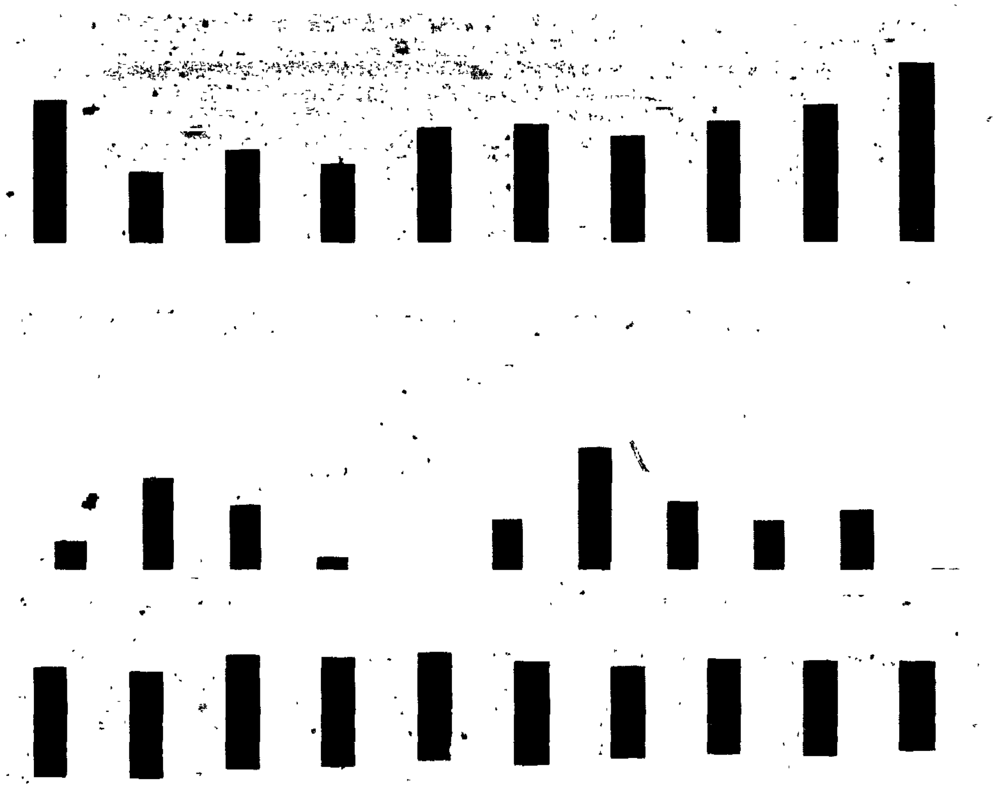


tasks are included in this amount and accounted for \$52,000,000 or 18% of the total Laboratory activity. Funding for the reporting period for construction of facilities totaled \$5,400,000.

Between July 1, 1976, and September 30, 1977, JPL conducted more than 28,000 procurement transactions, representing obligations of \$197,500,000. Principal activities centered around the Voyager mission, the Seasat-A Project, and Tracking and Data Acquisition, Civil Systems, and Space Science Applications projects.

The Laboratory continued its efforts to recruit and employ minority and female candidates. Four predominantly black schools and three southwestern schools with significant Hispanic enrollments were among the 19 colleges and universities where the Laboratory actively recruited.

A career-counseling function has been added to the Professional Development staff so that professional career guidance may be offered to employees to encourage their further development toward stated goals.



Special Recognition

A considerable number of JPL personnel received special awards and recognition during the reporting period. These include.

W. H. Pickering, recently retired JPL Director, National Medal of Science, administered through the National Science Foundation; also the Delmer S. Fahrney Medal of The Franklin Institute.

NASA's annual honor awards program and the recognition of individual outstanding contributions to the Viking Project combined to bring about quite a large number of awards to JPL employees:

H. W. Norris, NASA Distinguished Service Medal.

R. L. Crabtree, G. N. Gianopulos, L. Kingsland, P. T. Lyman, W. J. O'Neil, R. A. Ploszaj, and A. E. Wolfe, NASA Outstanding Leadership Medal

C. B. Farmer, R. F. Landel, B. G. Lee, L. M. Mack, C. W. Snyder, and J. G. Williams, NASA Exceptional Scientific Achievement Medal.

J D. Acord, M. J. Alazard, A. Q. Berglund, B. Brown, W. J. Carley, R. Case, A. E. Cherniack, R. F. Collins, W. J. Castellana, R. C. Hastrup, K. Heftman, D. W. Johnston, W. H Kohl, J. R. Kolden, B. T. Larmen, R. E. Loesh, R. T. Mitchell, W. K. Moore, D J. Mudgway, W. H. Padgham, P. H. Roberts, K. H. Rourke, J. H Rupe, W. J. Schatz, J. R. Scull, J. P. Slonski, T. C. Sorensen, G. P. Textor, C. H. Uphoff, F. C. Vote, B. K. Wada, and K. S. Watkins, NASA Exceptional Service Medal.

In addition, NASA Group Achievement Awards, too numerous to list here, honored many others for participation in especially noteworthy accomplishments, including Viking and other selected activities.